Jet Propulsion Laboratory
California Institute of Technology

UTLS Composition Variability Associated with Modes of the Asian Monsoon

Michael J. Schwartz[1], Michelle L. Santee[1], Gloria L. Manney[2,3]

[1]Jet Propulsion Laboratory/California Institute of Technology

[2]Northwest Research Associates, [3]Department of Physics, New Mexico Institute of Mining and Technology

The 3nd Workshop of Atmospheric Composition and the Asian Monsoon

Guangzhou, China

June 7, 2017

Modes of the Asian Summer Monsoon Anticyclone circulation center

- Numerous studies (after Zhang et al. 2002) have characterized modes of the Asian summer Monsoon anticyclone (ASMA) using the location of maximum GPH along the east-west null in zonal 100-hPa wind between the westerlies on the north side and easterlies on the south side of the circulation.
- 100-hPa GPH from both NCEP-1 and NCEP-2 show a striking bimodality in the longitudinal location of this GPH maximum, with distinct “Tibetan” and ”Iranian” modes.

- Yan et al. 2011 composited MLS 100-hPa composition measurements using this bimodal index.

- Nützel et al. 2016 showed that this striking bimodality is not seen in modern reanalyses such as MERRA, ERA-I and JRA-55.

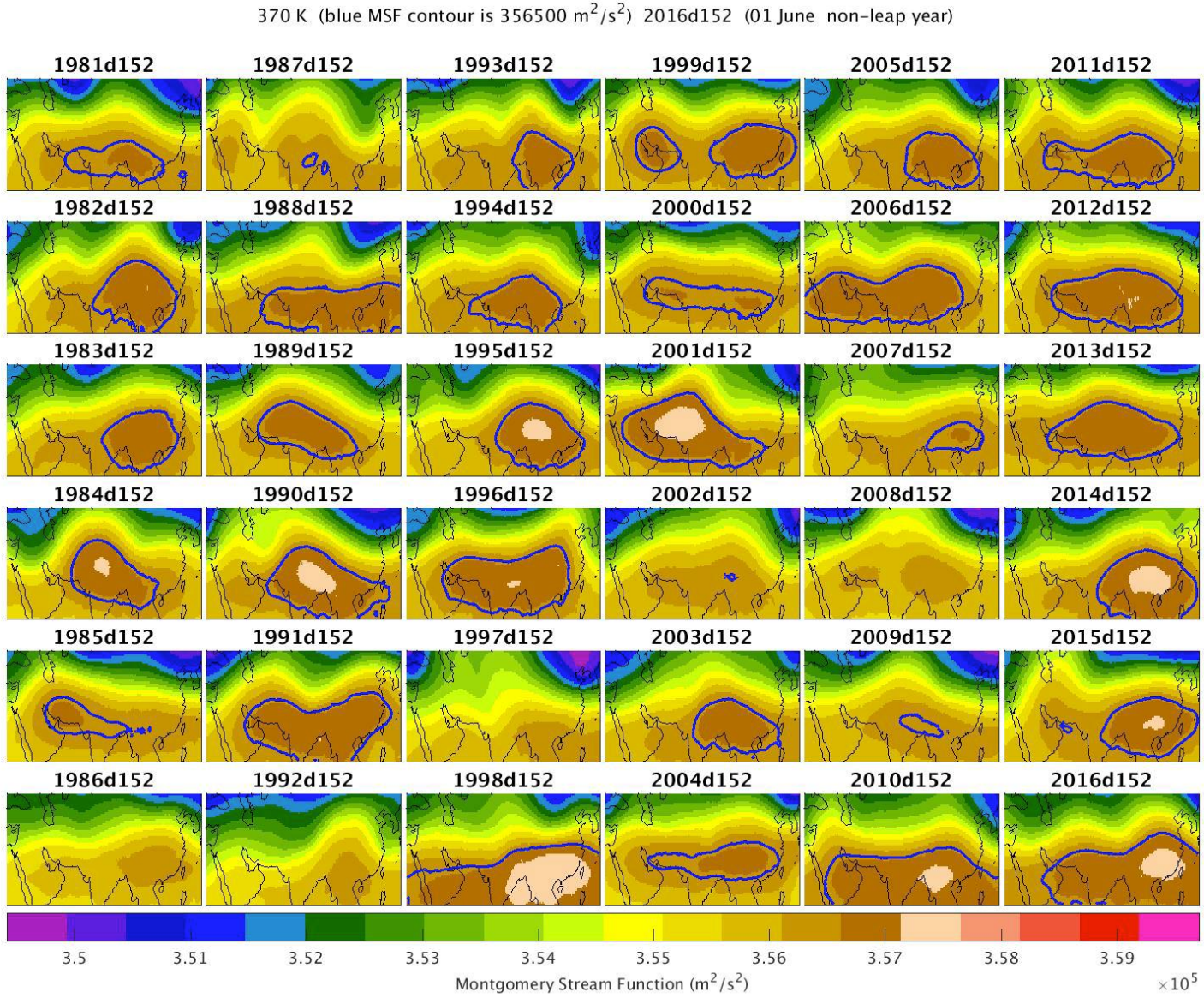
- Here, we examine two-dimensional modes of the ASMA using MERRA-2 and relate them to associated variability in version 4.2 MLS composition measurements that have been interpolated to isentropic surfaces.

- We use Montgomery stream function (MSF) rather than GPH because we want to do analysis of advected tracers on isentropic surfaces. MSF is the stream function of geostrophic winds on isentropic surfaces, analogous to GPH on isobaric surfaces.
- MSF = $g\,z + c_p\,T$ (where g is gravitational acceleration, z is height, c_p is specific heat, T is temperature)

- We will focus on the 370K isentropic level (147—100 hPa in the ASMA).

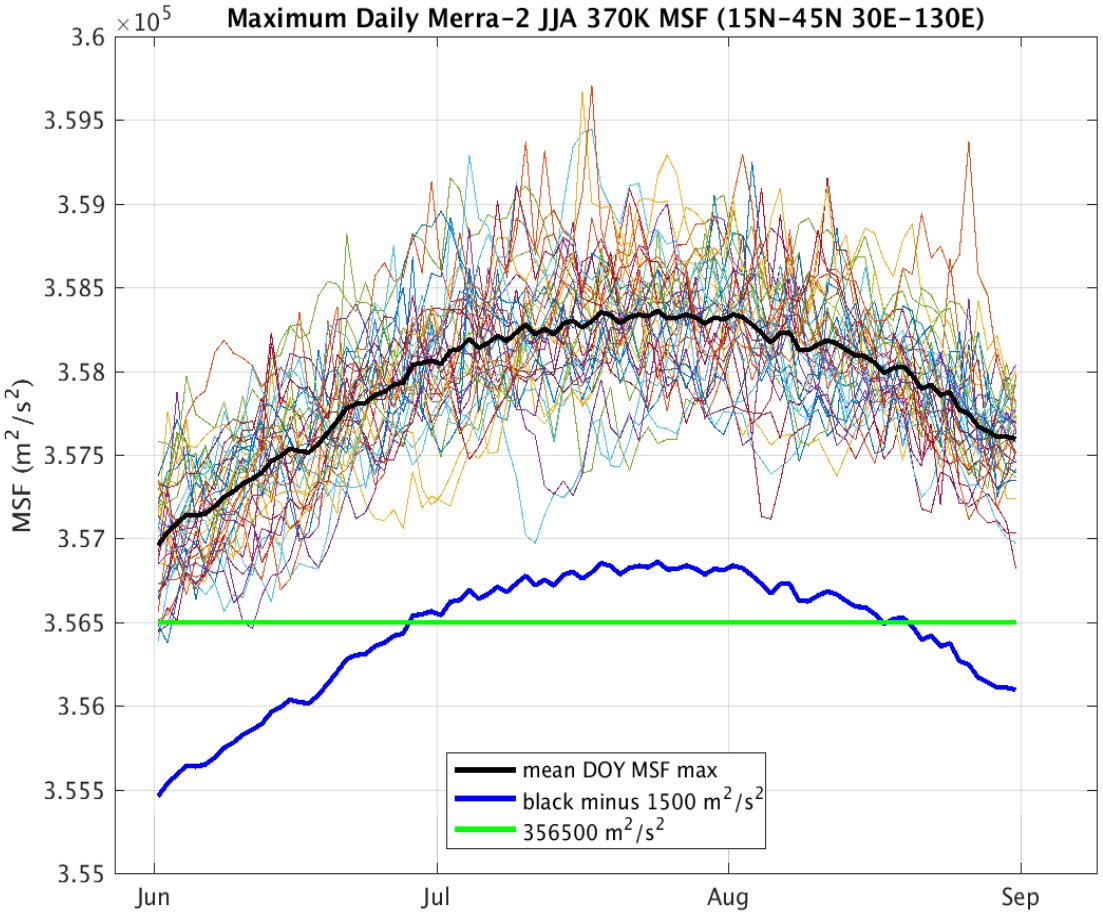
- Here we show 36 years of Merra-2 370K MSF for 15N-45N and 30E-130E for noon for June 1.

- We are interested in the locations of the circulation centers, however the variance in these maps is largest along the northern edge, where there are sharp gradients across the STJ.
- We can focus analysis on the variance around the circulation centers by forbidding map values to drop below a “floor”.
- The blue contour (MSF=356,500 m^2/s^2) roughly marks the boundary of confined circulation that traps constituents at this level (Santee et al. 2017).



- Daily maximum 370K MSF values within the monsoon box are shown for 37 years of MERRA-2 reanalysis.
- The black line is the 37-year average.
- The green line is 356,500 m^2/s^2 contour shown in blue on the previous maps and that typically delineates confinement of MLS constituents at 370K.
- Minimum values within the study box can be as low as 350,000 m^2/s^2 in June (10 ticks below the bottom of the figure) and as low as 352,000 m^2/s^2 in August (6 ticks below the bottom of the plot.)

- The green line is used as the “floor” in the following EOF analyses, but the blue line, 1500 m^2/s^2 below the mean maximum, has also been used as a “floor” in exploratory EOF analyses.

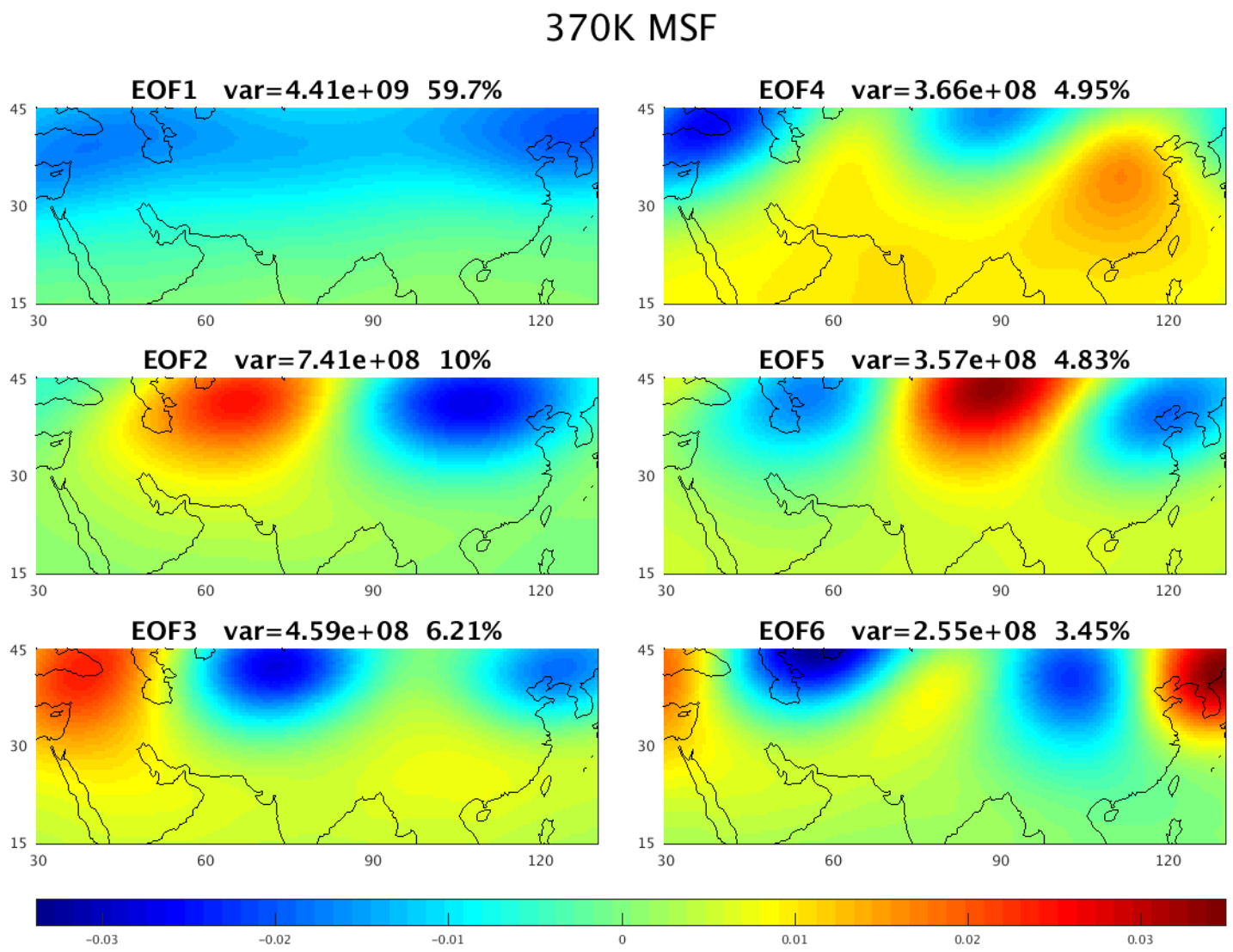


Empirical Orthogonal Function (EOF) Analysis

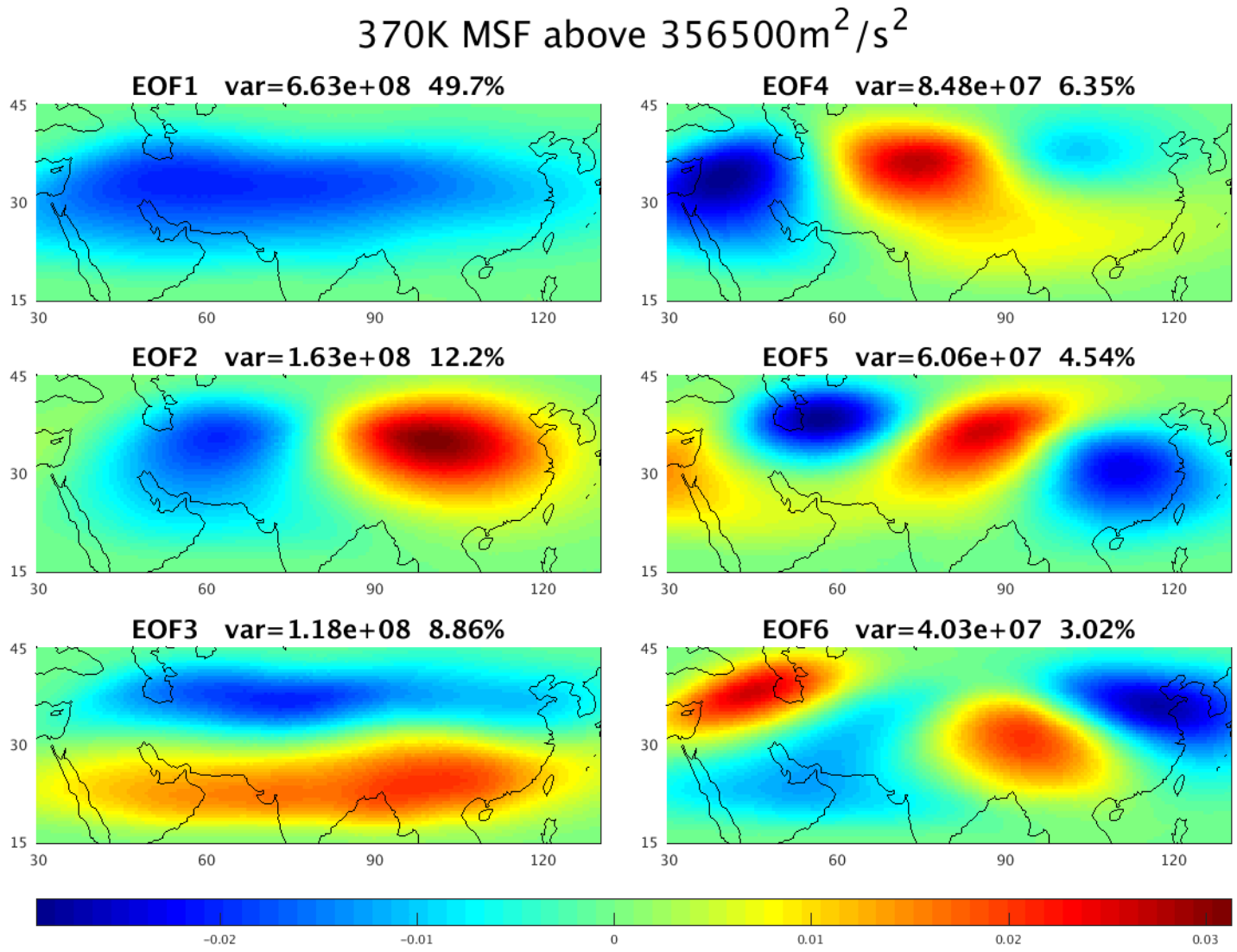
- Each map is a “vector”. At Merra-2 resolution in our 30E—130E, 15N—45N study box we have:
  61 lats x 161 lons = 9821 elements in a vector and 92 JJA noon observations/year * 37 years = 3404 daily observation.
- The covariance matrix (lon x lat) X (lon x lat) about the mean map has the variance of each map location on its diagonal and the covariance of each pair of map locations as off-diagonals.
- The eigenvectors of the covariance matrix are the EOFs. The eigenvalues are the variance captured by a given EOF. The time-varying amplitude of an EOF (positive or negative) is its principal component (PC).
- A small number of EOFs can capture most of the MSF variance.

- The PCs (the timeseries of coefficients) are also orthogonal to one another and can be used to weight the MLS daily composition measurements. Individual composition measurements (not maps) could be weighted by PC of a given mode, then these weighted values could be mapped to show the correlation of the composition field with the monsoon mode.

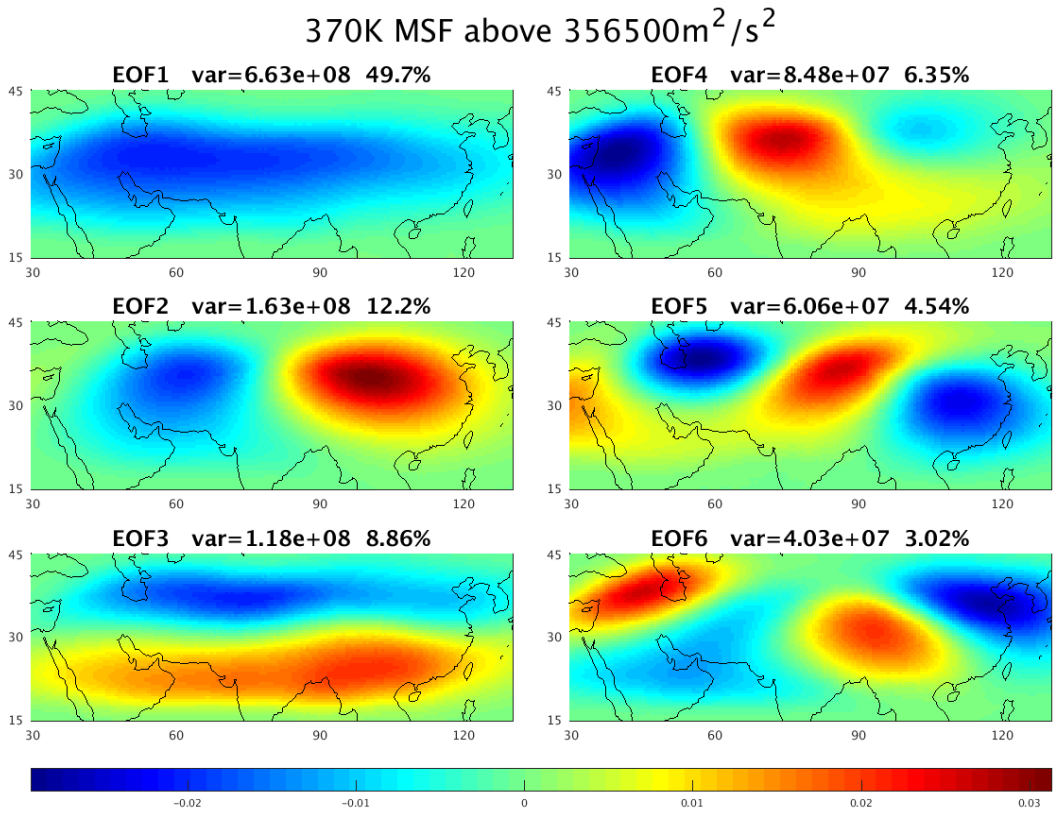
- These are the six leading EOFs calculated without using a “floor”.
- They are dominated by variability along the STJ.

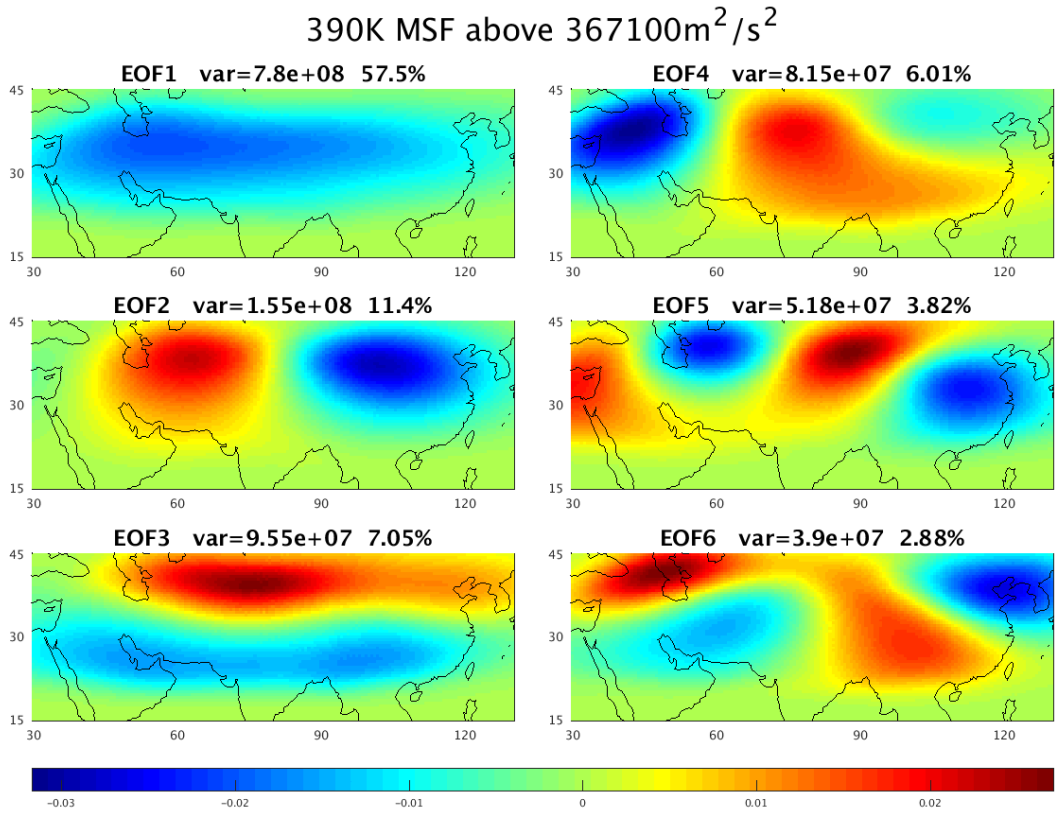


- These are the six leading EOFs from a covariance matrix calculated with a fixed “floor” at 356,500 m^2/s^2 that is set prior to removal of the mean.
- The leading mode is a weakening (strengthening for negative PC) of the vortex. This mode has a strong seasonal cycle.
- The second mode is reminiscent of the NCEP bimodality, but the eastern maximum is further east.
- The third mode captures north-south shifts, which also have a seasonal component though, by definition, EOF3 is orthogonal to EOF1 and PC3 is uncorrelated with PC1.
- These 6 modes capture 84% of the MSF variance in the 37 year record.



- Correlations between the 370K and 390K EOFs range from 98% for EOF1 to 82% for EOF6





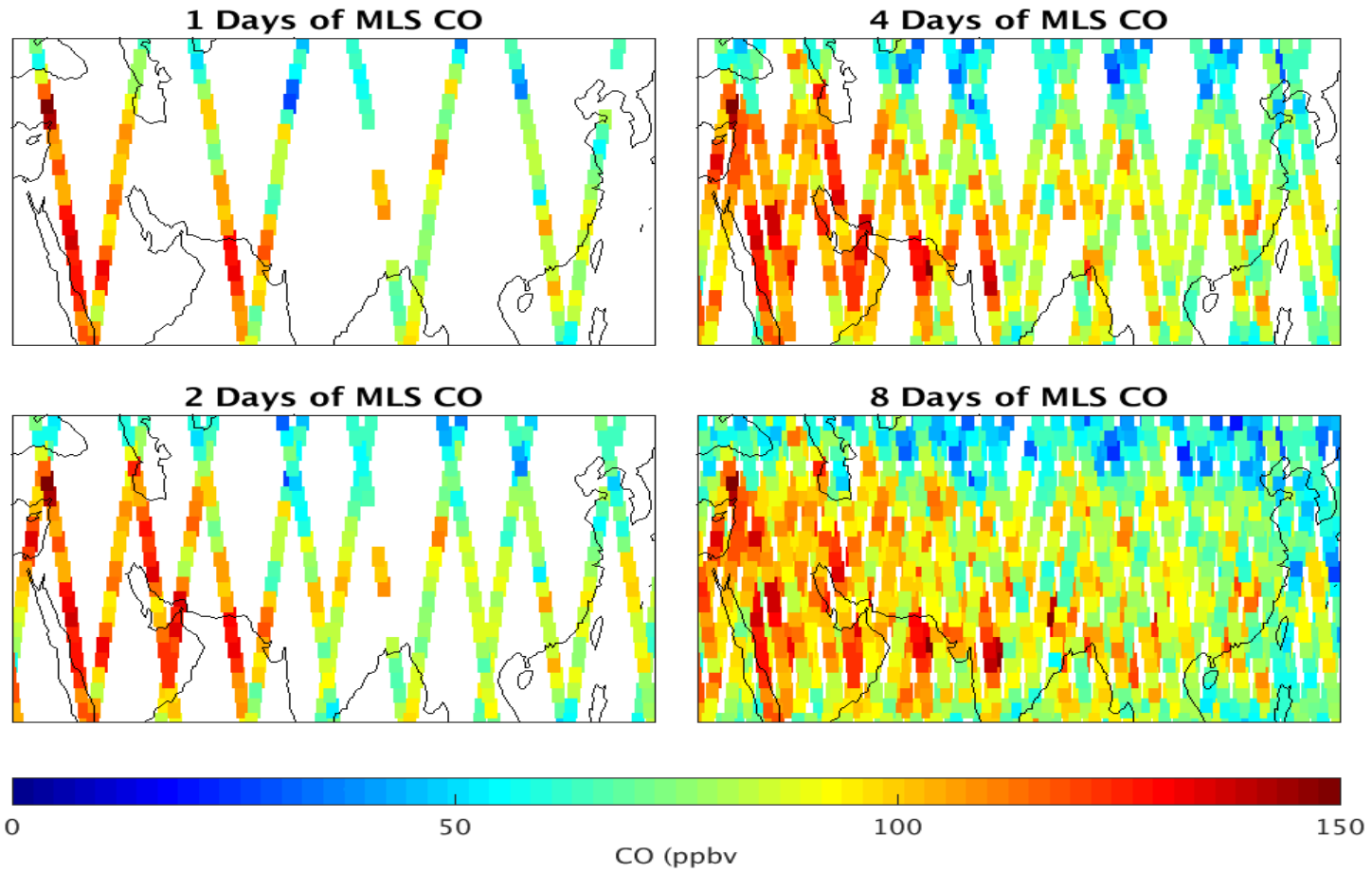
MLS Sampling

- The Aura Microwave Limb sounder (MLS) has collected almost 13 years of composition measurements from the UT through the middle atmosphere with a 16-day orbital repeat cycle.

- In the ASMA, MLS measures tropospheric tracers: H_2O, CO, CH_3Cl CH_3CN, CH_3OH and stratospheric tracers O_3 , HNO_3 , HCl as well as IWC (see Santee et al. 2017)
- Here we will focus on CO, but techniques are generally applicable to other species.

- Using 4 days of data seems a reasonable compromise between spatial sparsity and temporal blurring, but we need to ask:

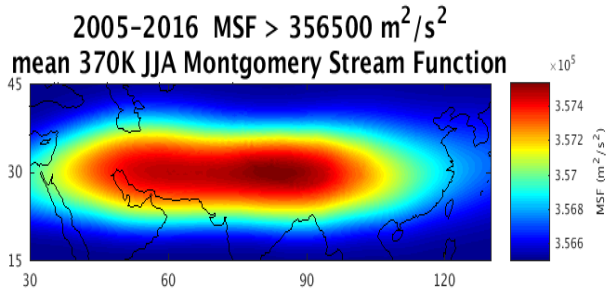
- To what extent does the MLS spatial/temporal sampling distort our determination of monsoon anticyclone modes?

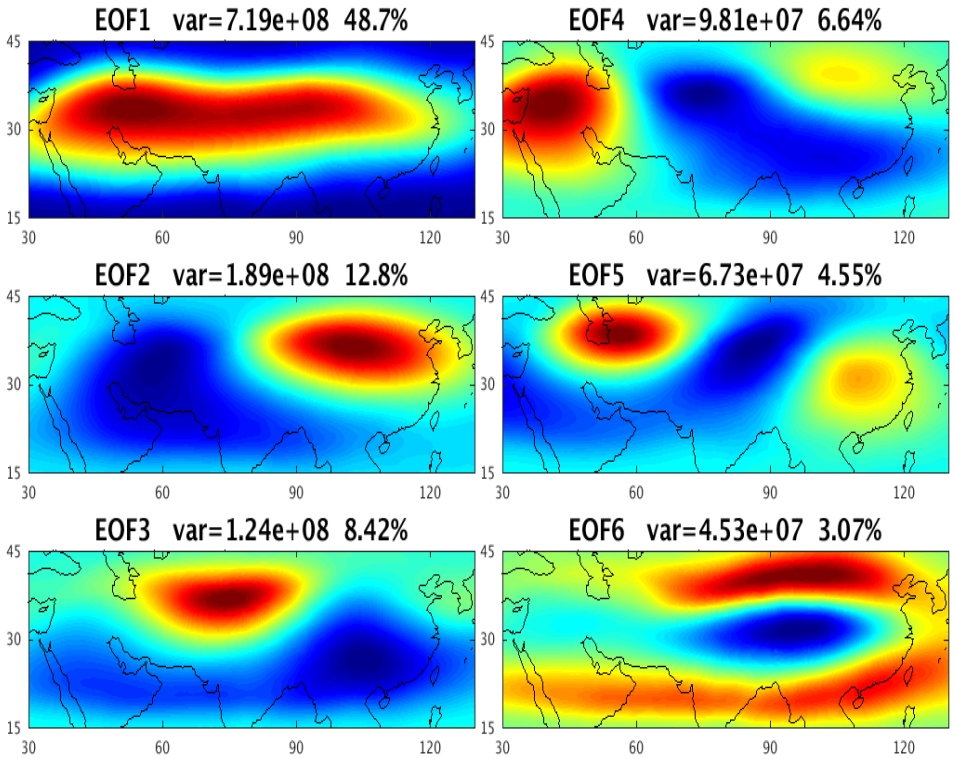


MSF JJA 2005—2016

from MERRA-2 full-resolution, noon daily maps

0.5° lat x 0.625° lon (9821 element maps) (12x92=1104 observations)

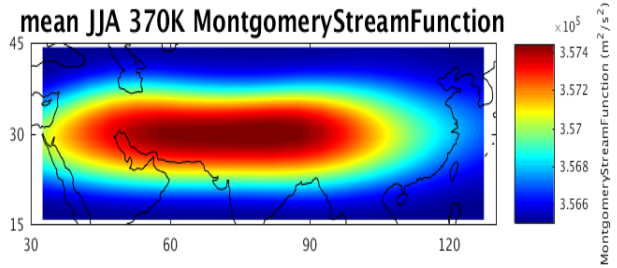


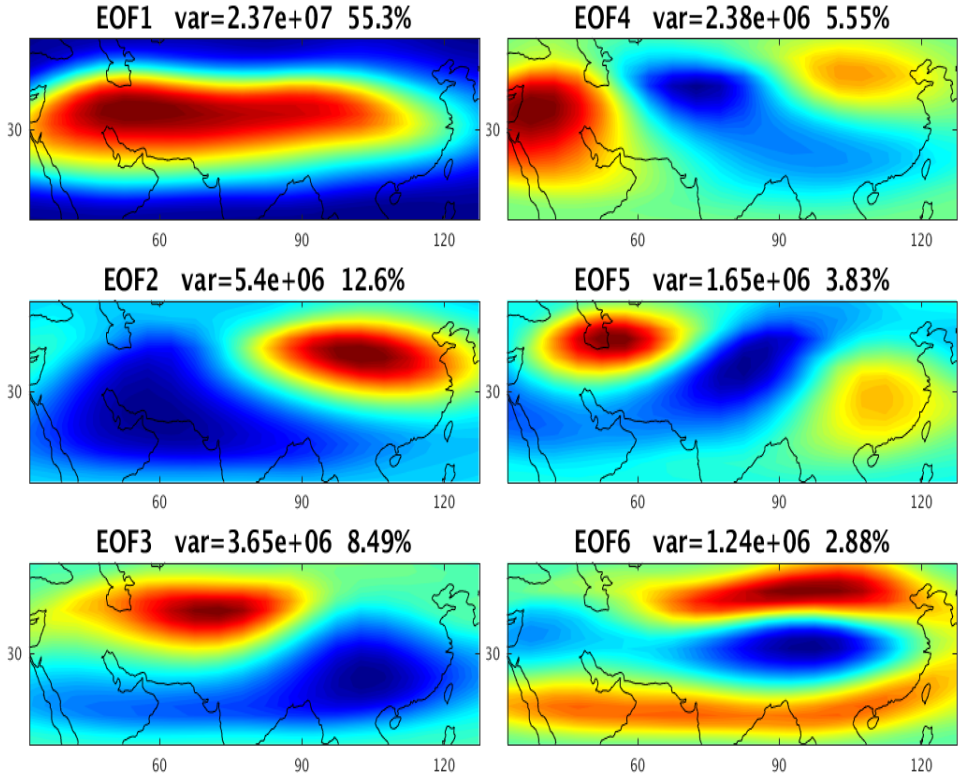


MSF JJA 2005—2016

from 4-day maps from MSF sampled as MLS

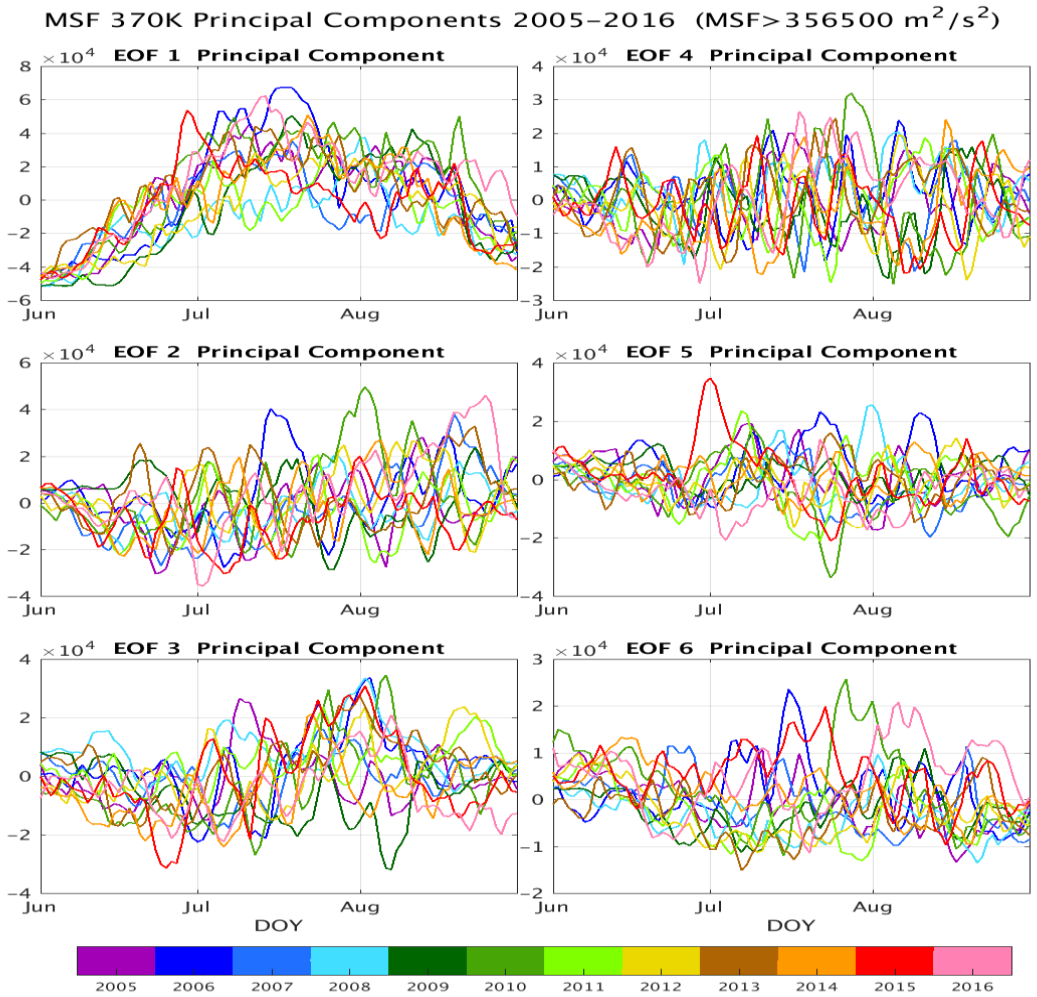
1.5° lat x 5° lon (20x20=400 map) (12x23=276 4-day maps)



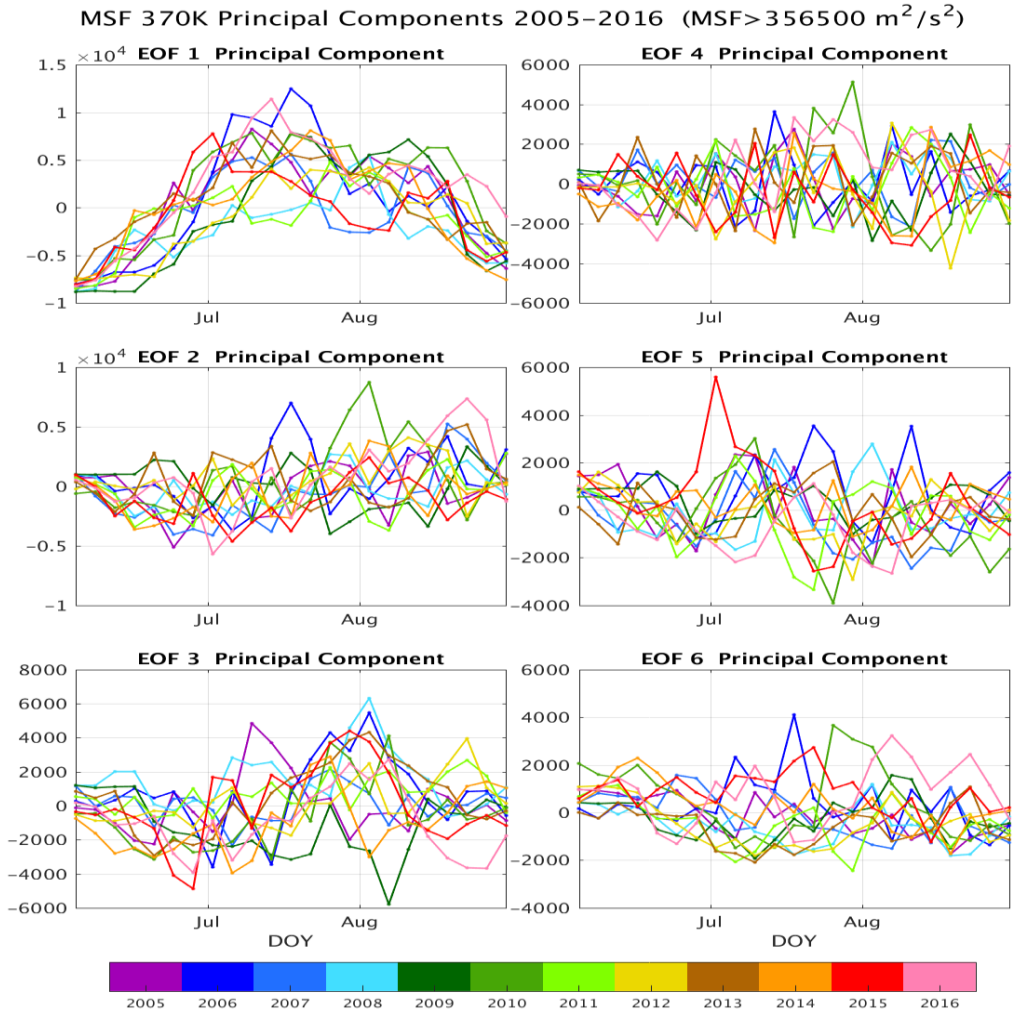


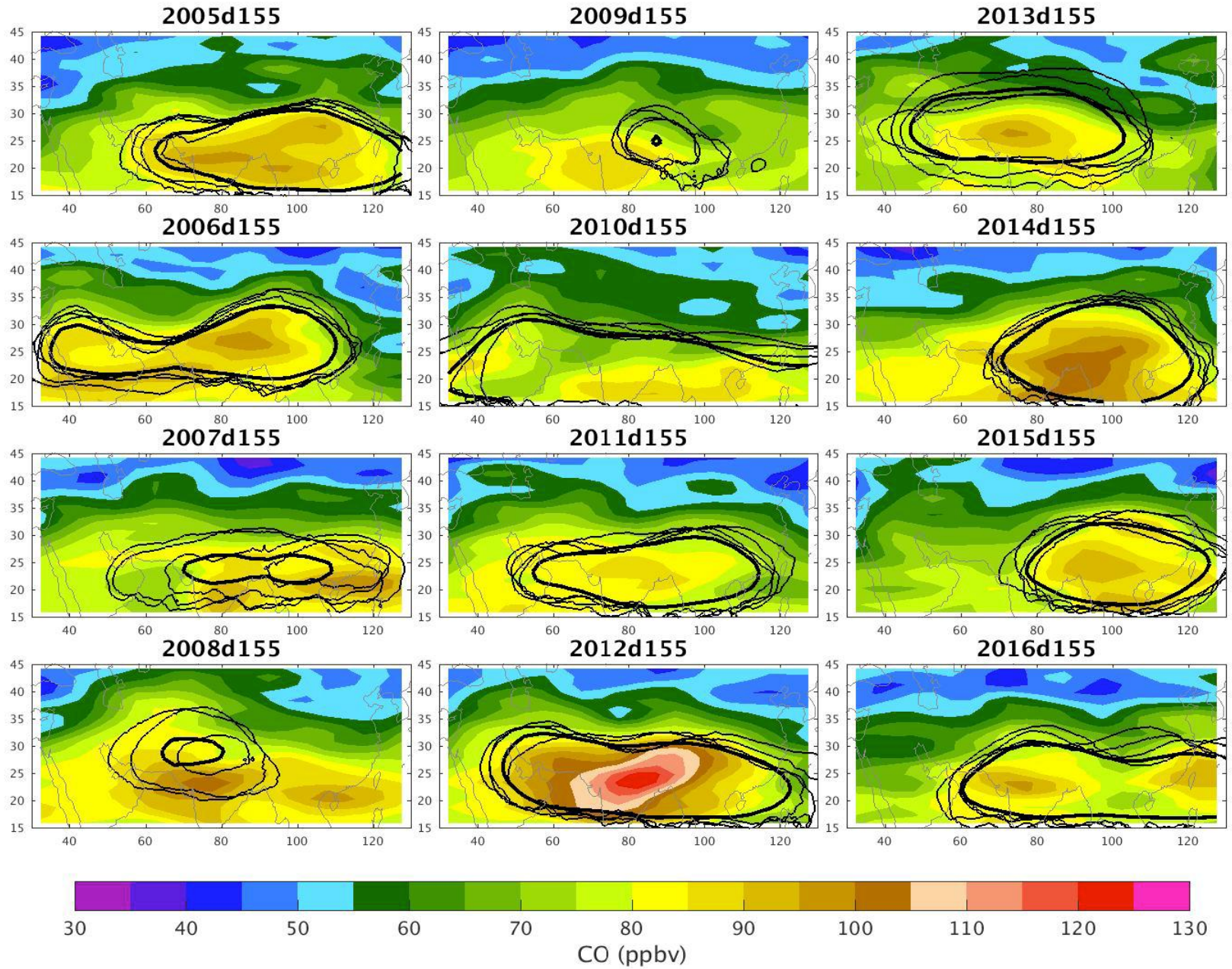
Principal Components

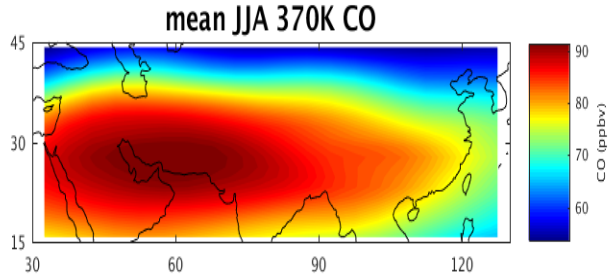
MSF JJA 2005—2016
from MERRA-2 full-resolution daily maps

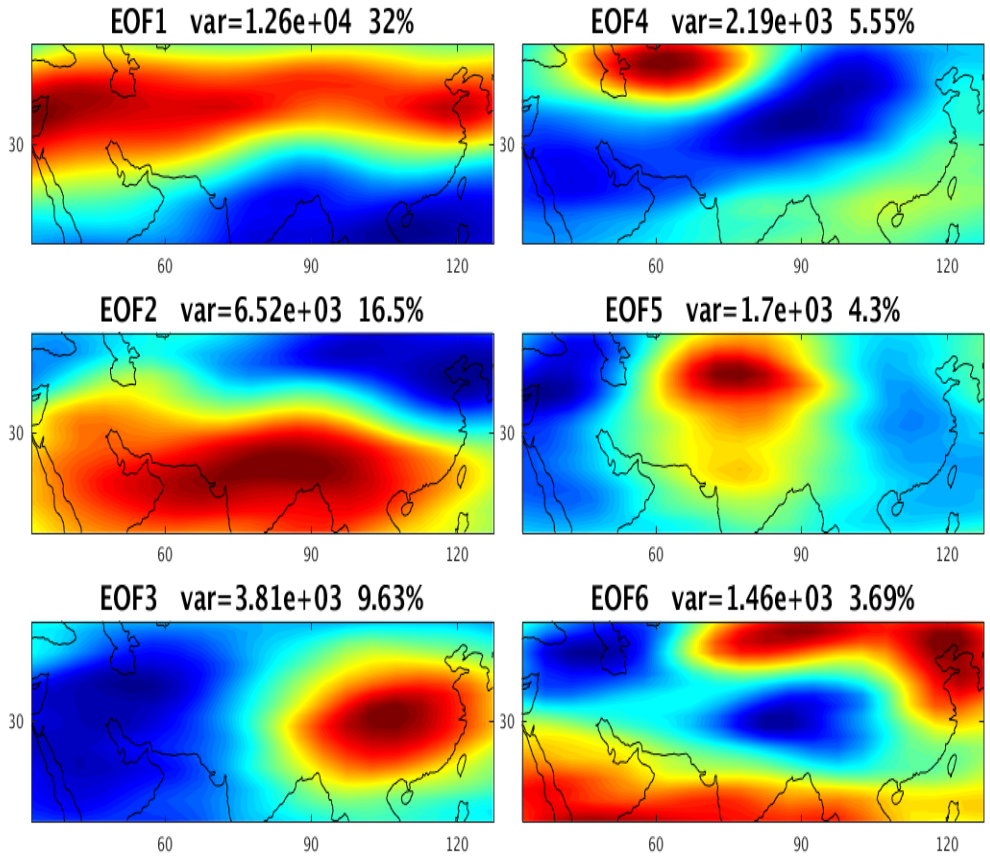


MSF JJA 2005—2016
from 4-day maps from MSF sampled as MLS

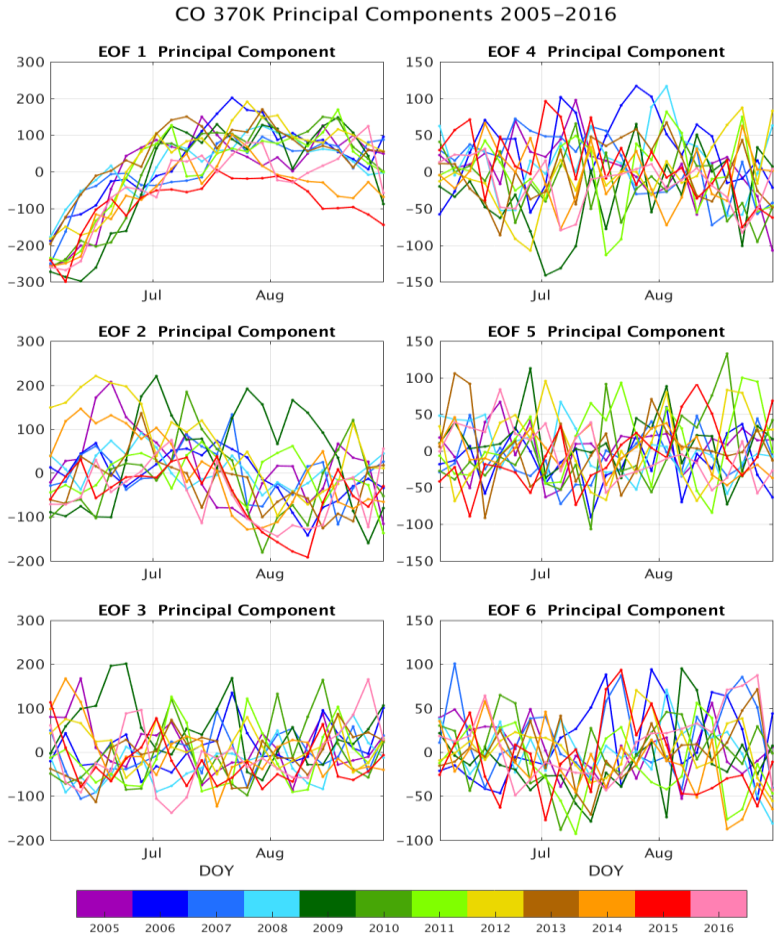



370 K CO DOY 155 (04 June non-leap year) (Black MSF contour is 356500 m^2/s^2)
2005d155
2009d155
2013d155
2006d155
2010d155
2014d155
2007d155
2011d155
2015d155
2008d155
2012d155
2016d155
30 40 50 60 70 80 90 100 110 120 130
CO (ppbv)



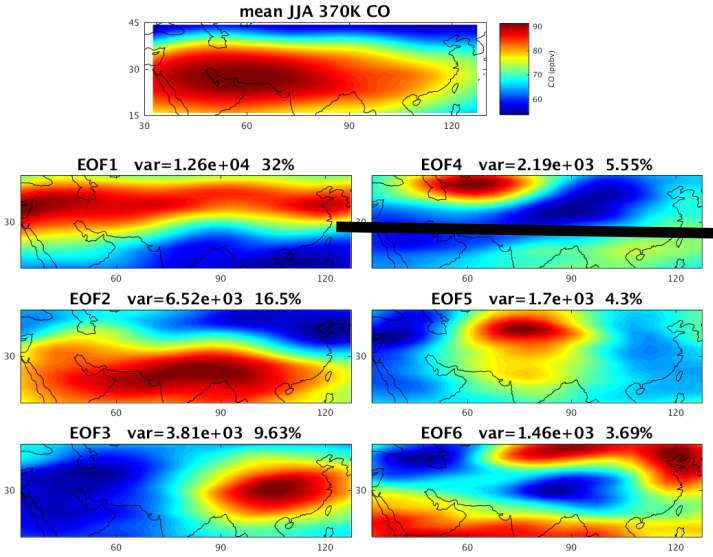


- The leading 6 EOF capture 72% of CO variability
- Association of modes with physical processes is a work in progress



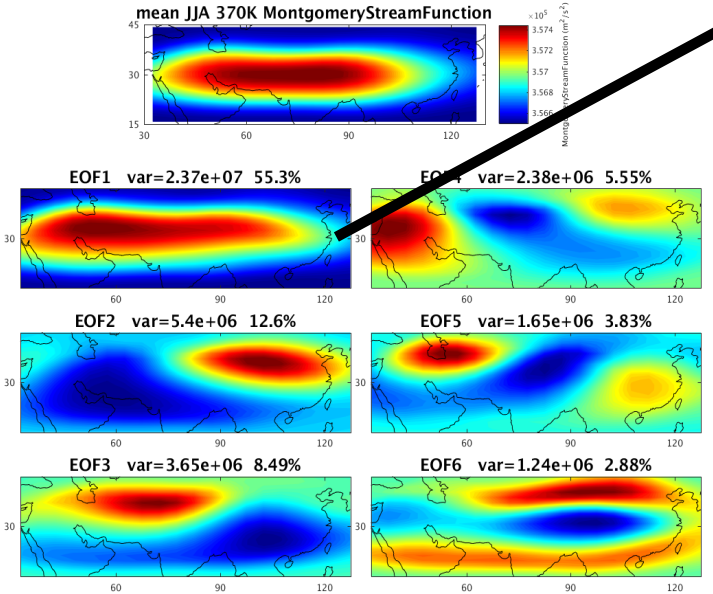
Joint CO + MSF (each with unit variance)
Vector has (20 lons x 20 lats x 2) elements

CO



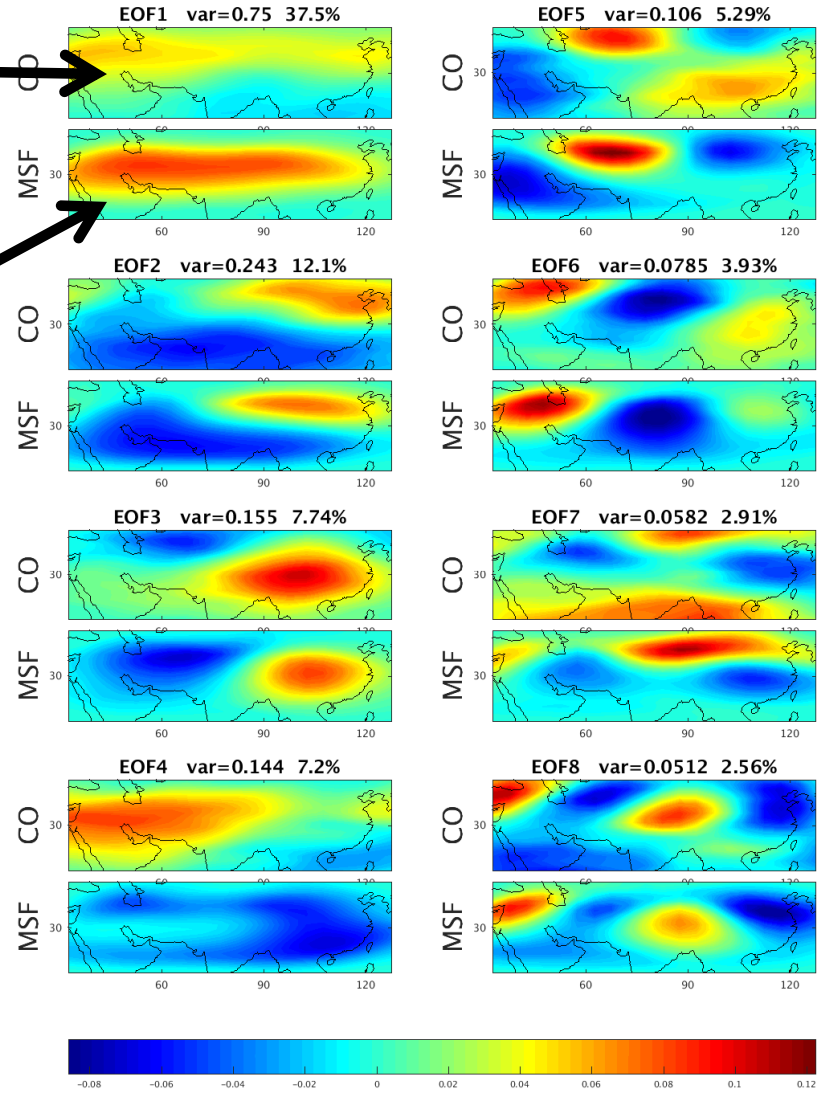
72% of σ^2
in 6 CO PCs

MSF



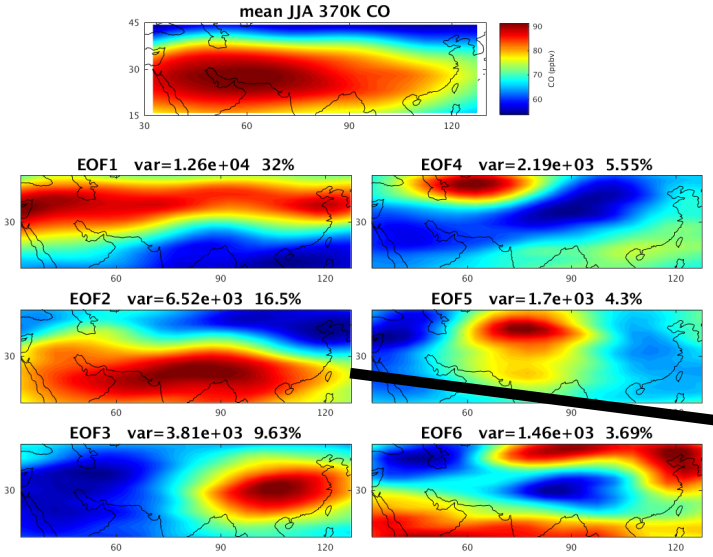
89% of σ^2
In 6 MSF PCs

Joint EOFs of CO and MSF

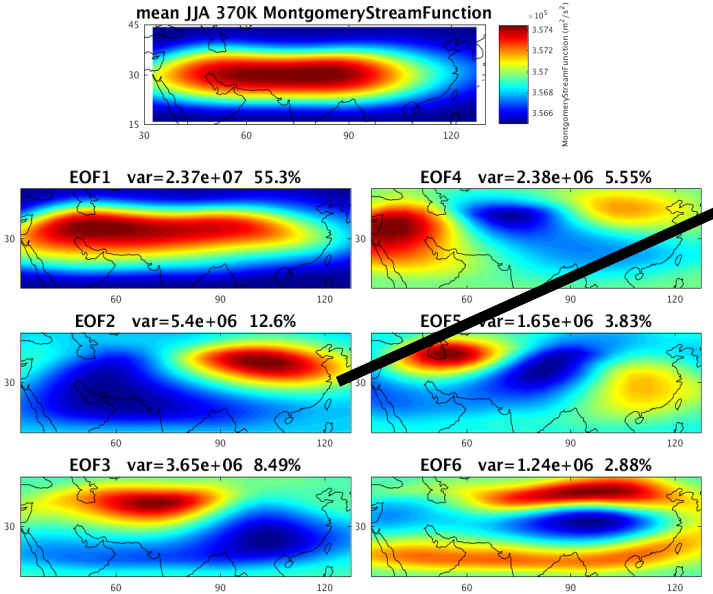


79% of σ^2
In 8 joint
CO+MSF PCs

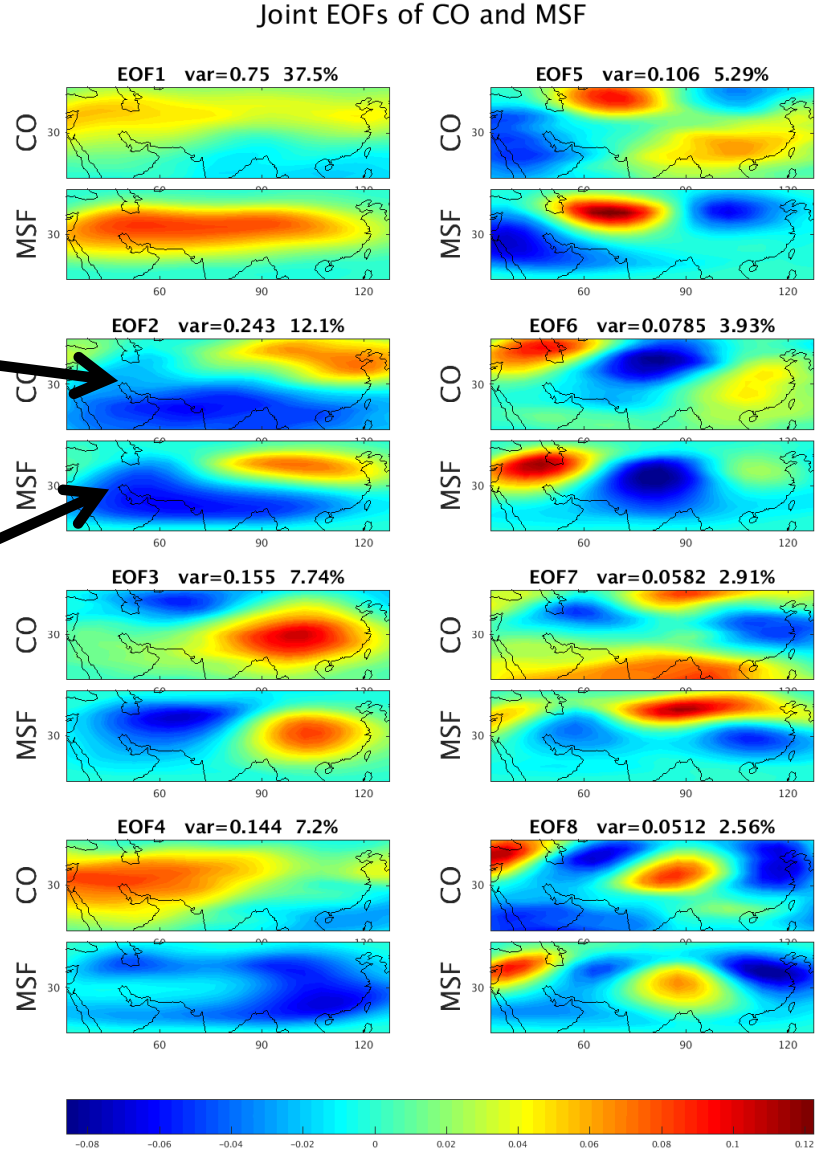
CO

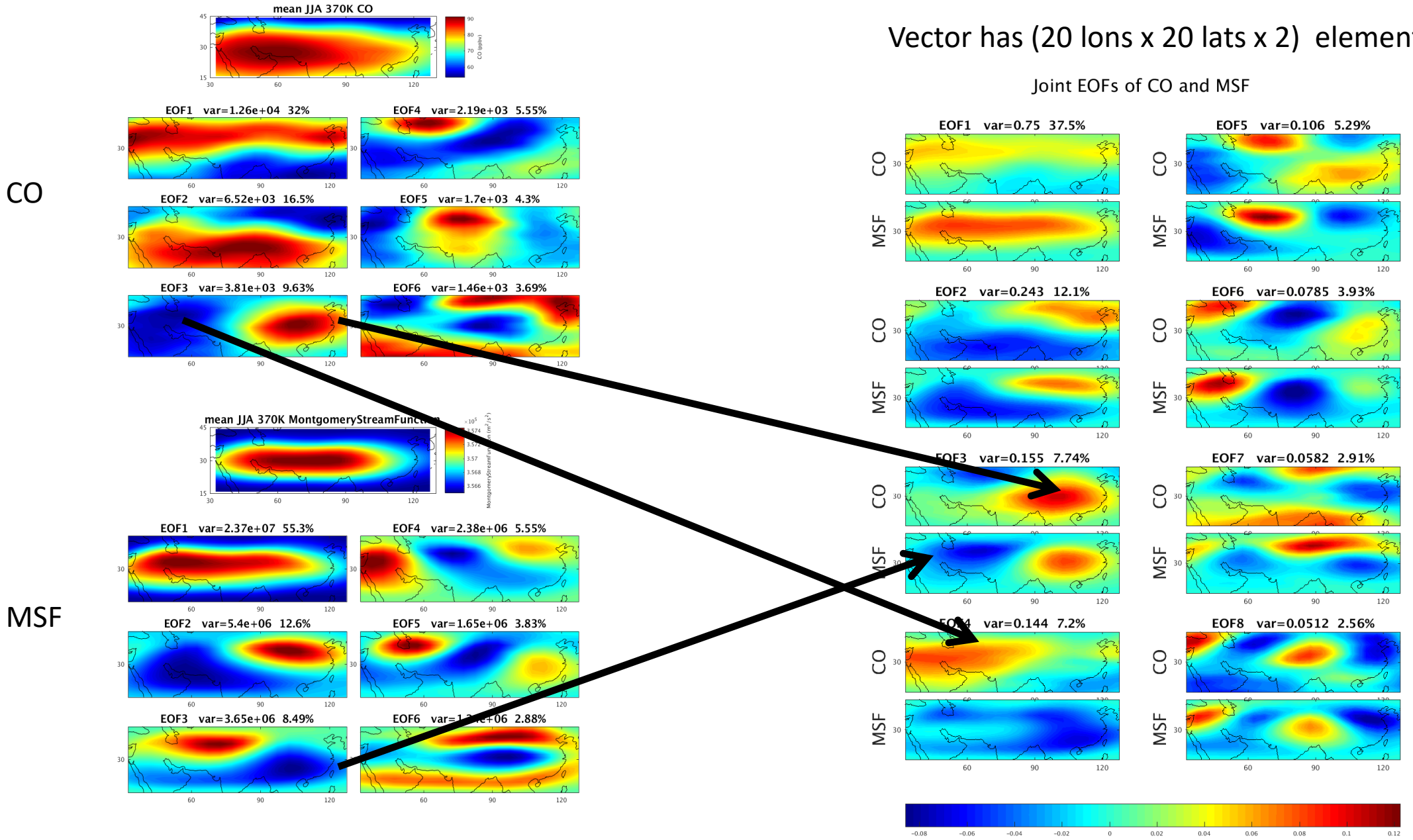


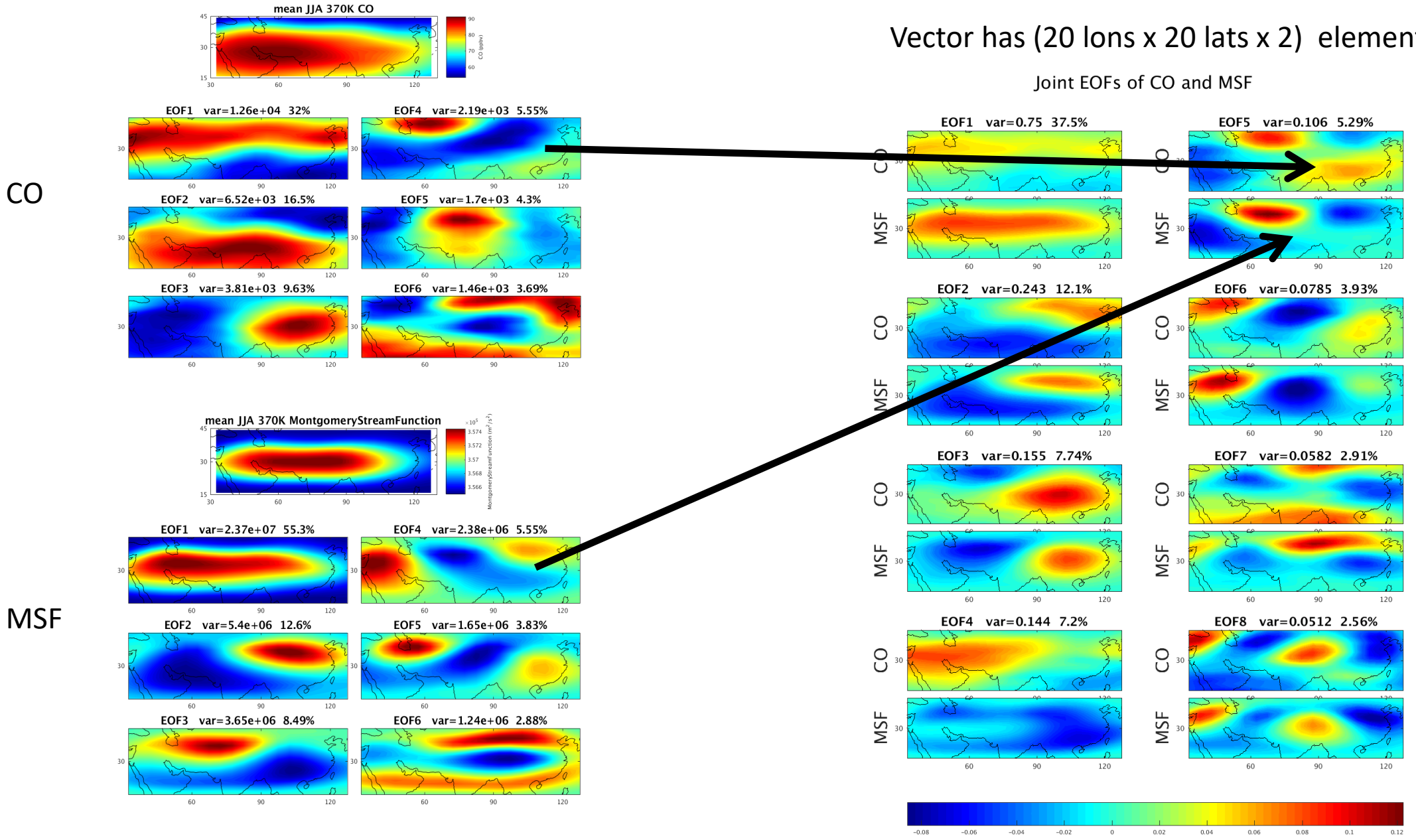
MSF



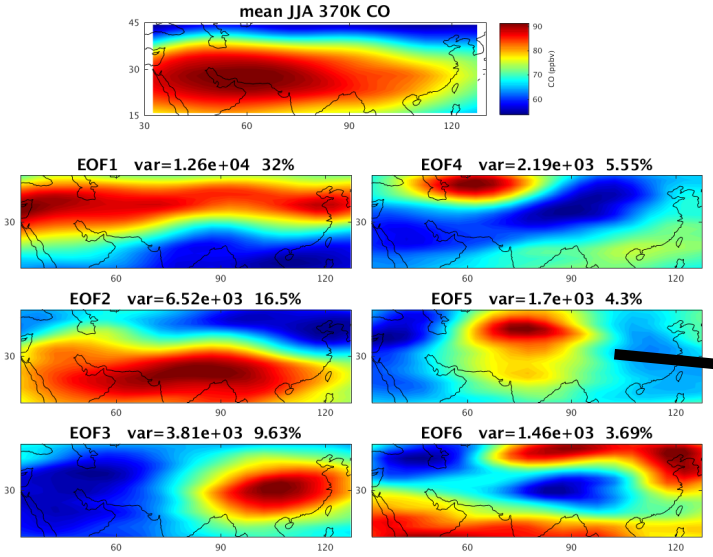
Vector has (20 lons x 20 lats x 2) elements



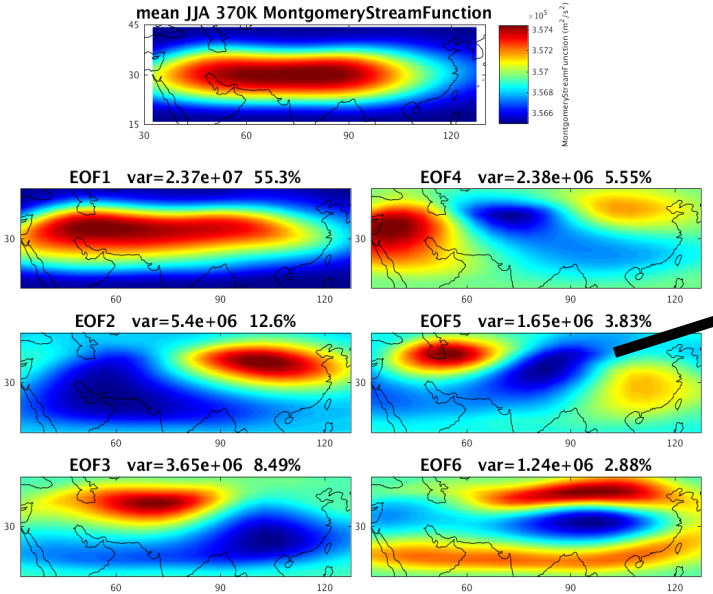

Vector has (20 lons x 20 lats x 2) elements
Joint EOFs of CO and MSF
CO
MSF
mean JJA 370K CO
EOF1 var=1.26e+04 32%
EOF4 var=2.19e+03 5.55%
EOF2 var=6.52e+03 16.5%
EOF5 var=1.7e+03 4.3%
EOF3 var=3.81e+03 9.63%
EOF6 var=1.46e+03 3.69%
mean JJA 370K MontgomeryStreamFunct
EOF1 var=2.37e+07 55.3%
EOF4 var=2.38e+06 5.55%
EOF2 var=5.4e+06 12.6%
EOF5 var=1.65e+06 3.83%
EOF3 var=3.65e+06 8.49%
EOF6 var=1.3
e+06 2.88%
EOF1 var=0.75 37.5%
EOF5 var=0.106 5.29%
EOF2 var=0.243 12.1%
EOF6 var=0.0785 3.93%
EOF3 var=0.155 7.74%
EOF7 var=0.0582 2.91%
EOF4 var=0.144 7.2%
EOF8 var=0.0512 2.56%


Vector has (20 lons x 20 lats x 2) elements
Joint EOFs of CO and MSF
CO
MSF
mean JJA 370K CO
EOF1 var=1.26e+04 32%
EOF4 var=2.19e+03 5.55%
EOF2 var=6.52e+03 16.5%
EOF5 var=1.7e+03 4.3%
EOF3 var=3.81e+03 9.63%
EOF6 var=1.46e+03 3.69%
mean JJA 370K MontgomeryStreamFunction
EOF1 var=2.37e+07 55.3%
EOF4 var=2.38e+06 5.55%
EOF2 var=5.4e+06 12.6%
EOF5 var=1.65e+06 3.83%
EOF3 var=3.65e+06 8.49%
EOF6 var=1.24e+06 2.88%
EOF1 var=0.75 37.5%
EOF5 var=0.106 5.29%
EOF2 var=0.243 12.1%
EOF6 var=0.0785 3.93%
EOF3 var=0.155 7.74%
EOF7 var=0.0582 2.91%
EOF4 var=0.144 7.2%
EOF8 var=0.0512 2.56%

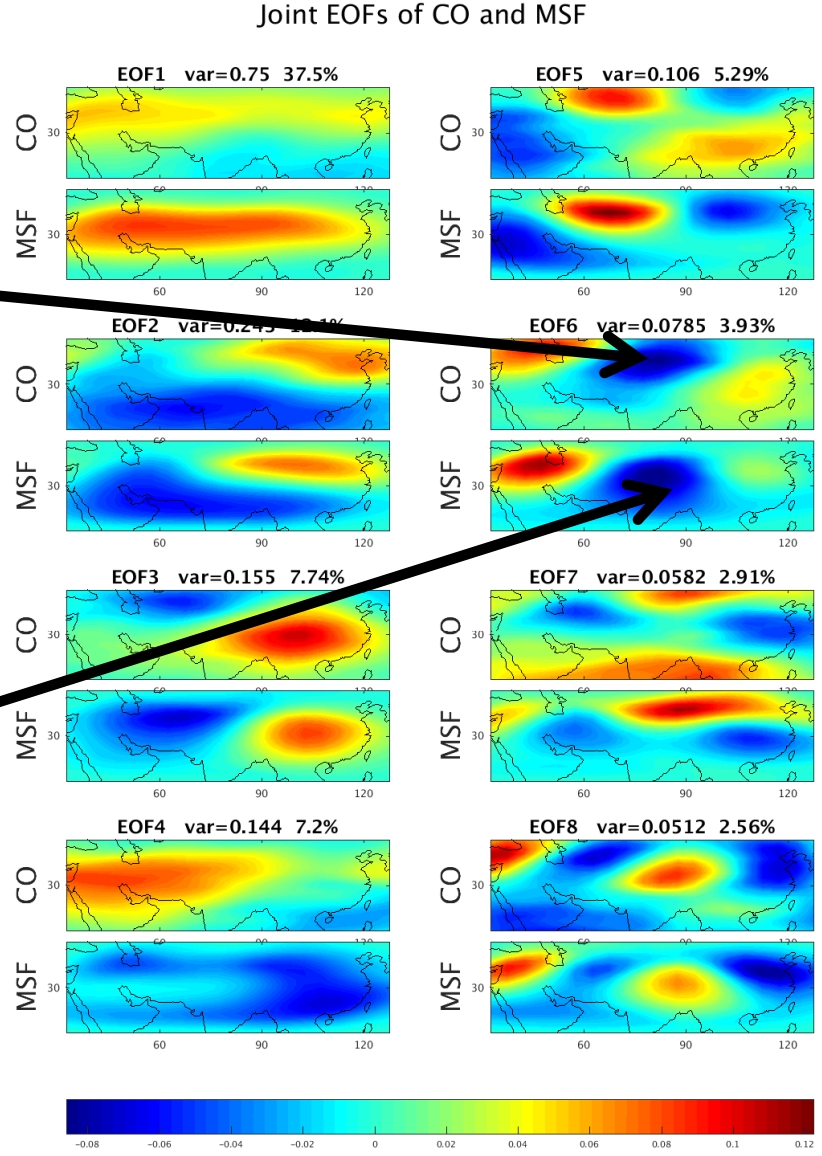
CO



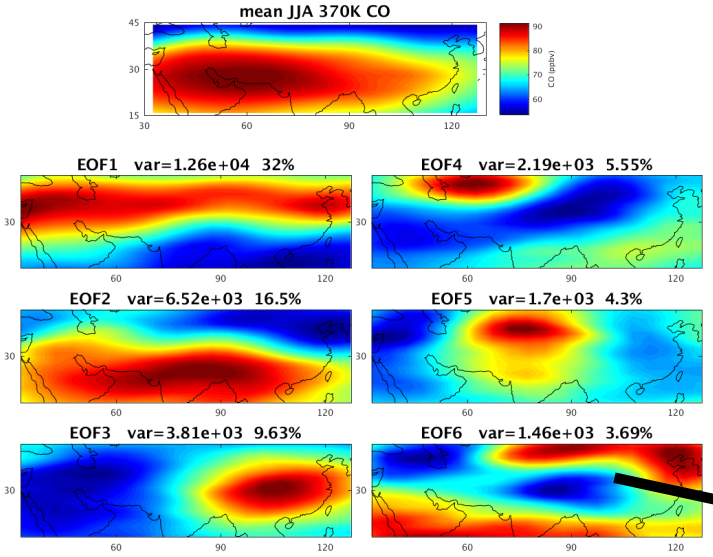
MSF



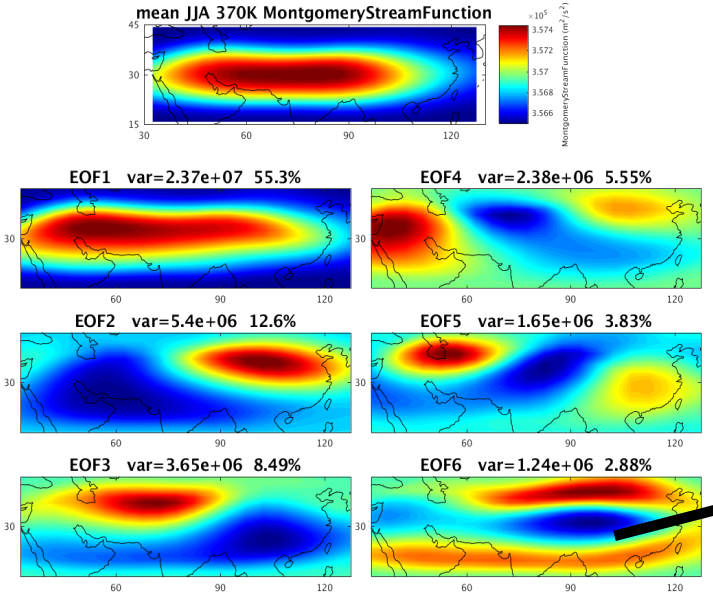
Vector has (20 lons x 20 lats x 2) elements



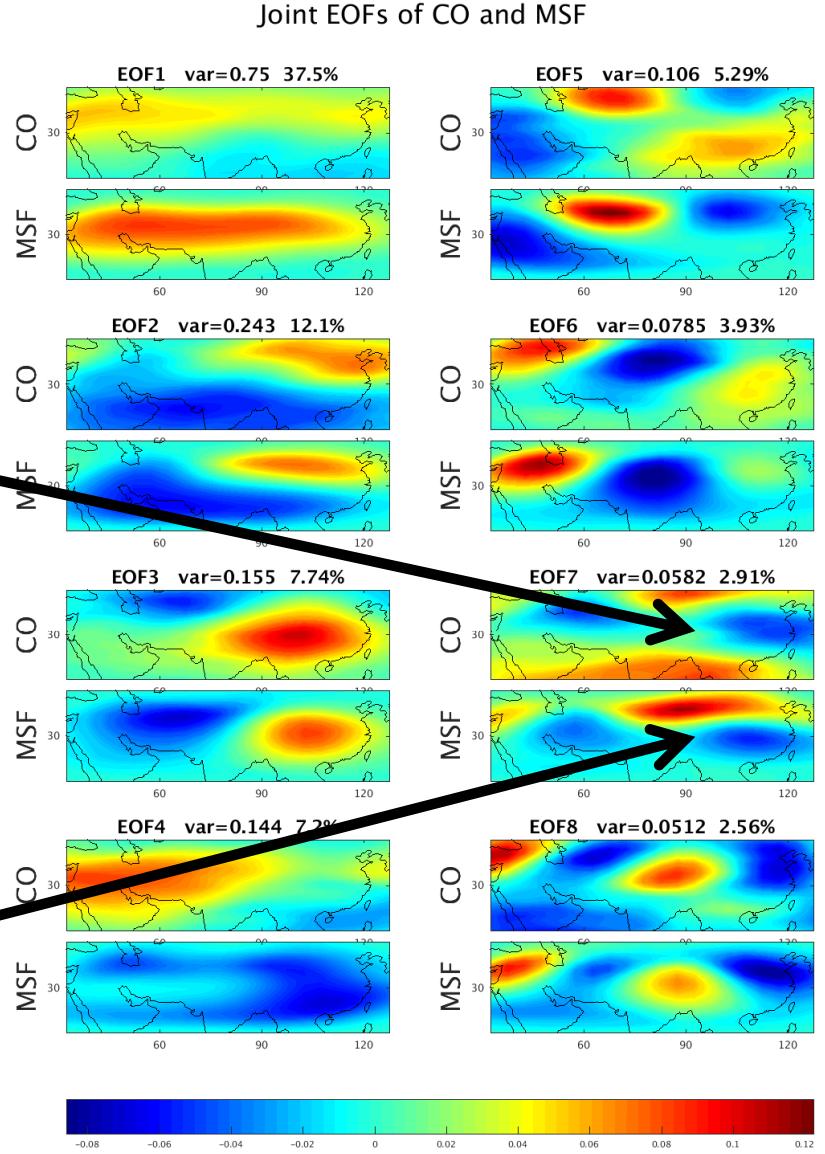
CO



MSF



Vector has (20 lons x 20 lats x 2) elements

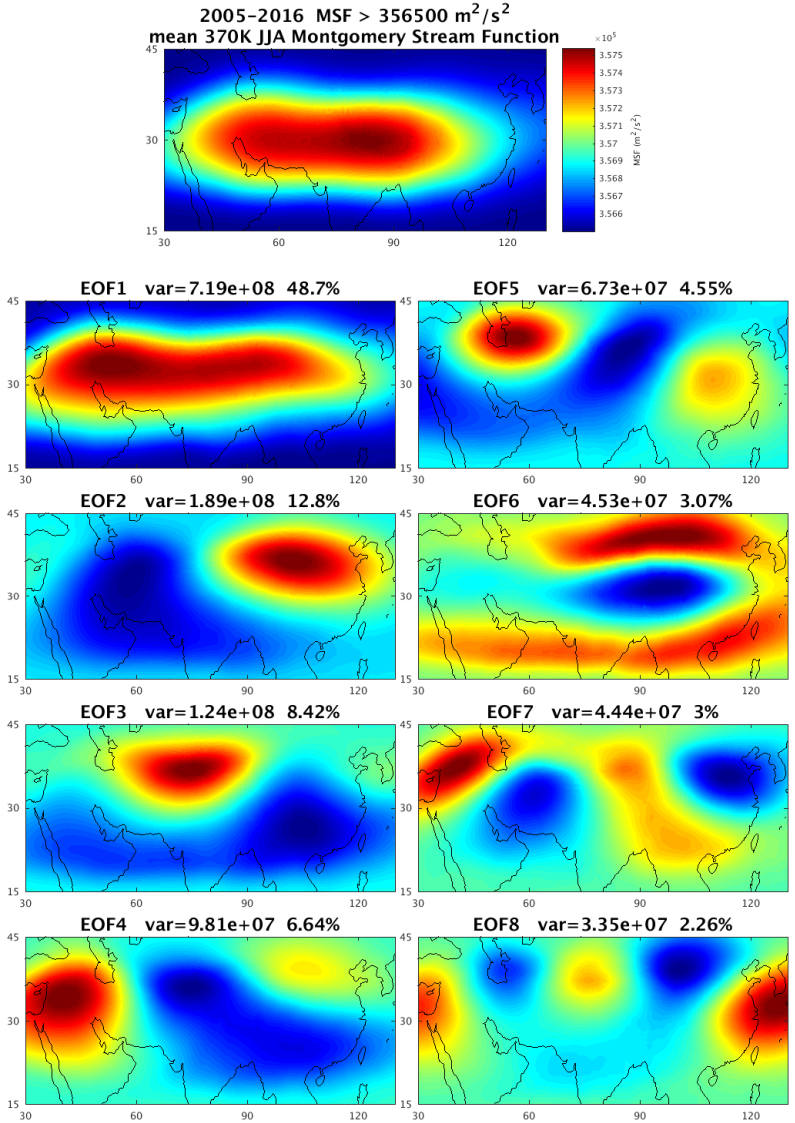


Conclusions

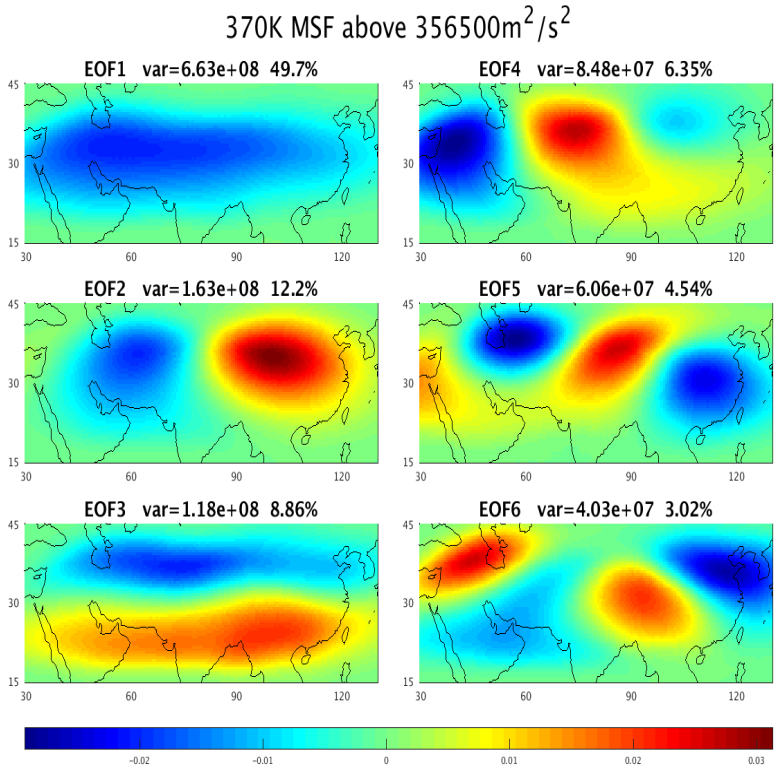
- The 370K ASMA circulation, as delineated by MSF contours, has considerable interannual, seasonal and daily time scale variability.
- Variance of MSF along the STJ must be suppressed if MSF is to provide modes of the ASMA circulation center variability. How best to do this is an area of current research, but the use of a simple floor has been demonstrated.
- The first six EOFs of JJA MSF capture 84--89% of variability (depending on years used).
- MLS spatial/temporal sampling does not substantially change the EOFs of PCs of MSF, although variance captured by a given EOF changes somewhat.
- Binning of MLS data into 4-day maps is reasonable for EOF analysis.
- Modes of MLS CO are substantially correlated with the modes of MSF.
- The interpretation of these modes in terms of physical processes is a work in progress.

Backup Slides

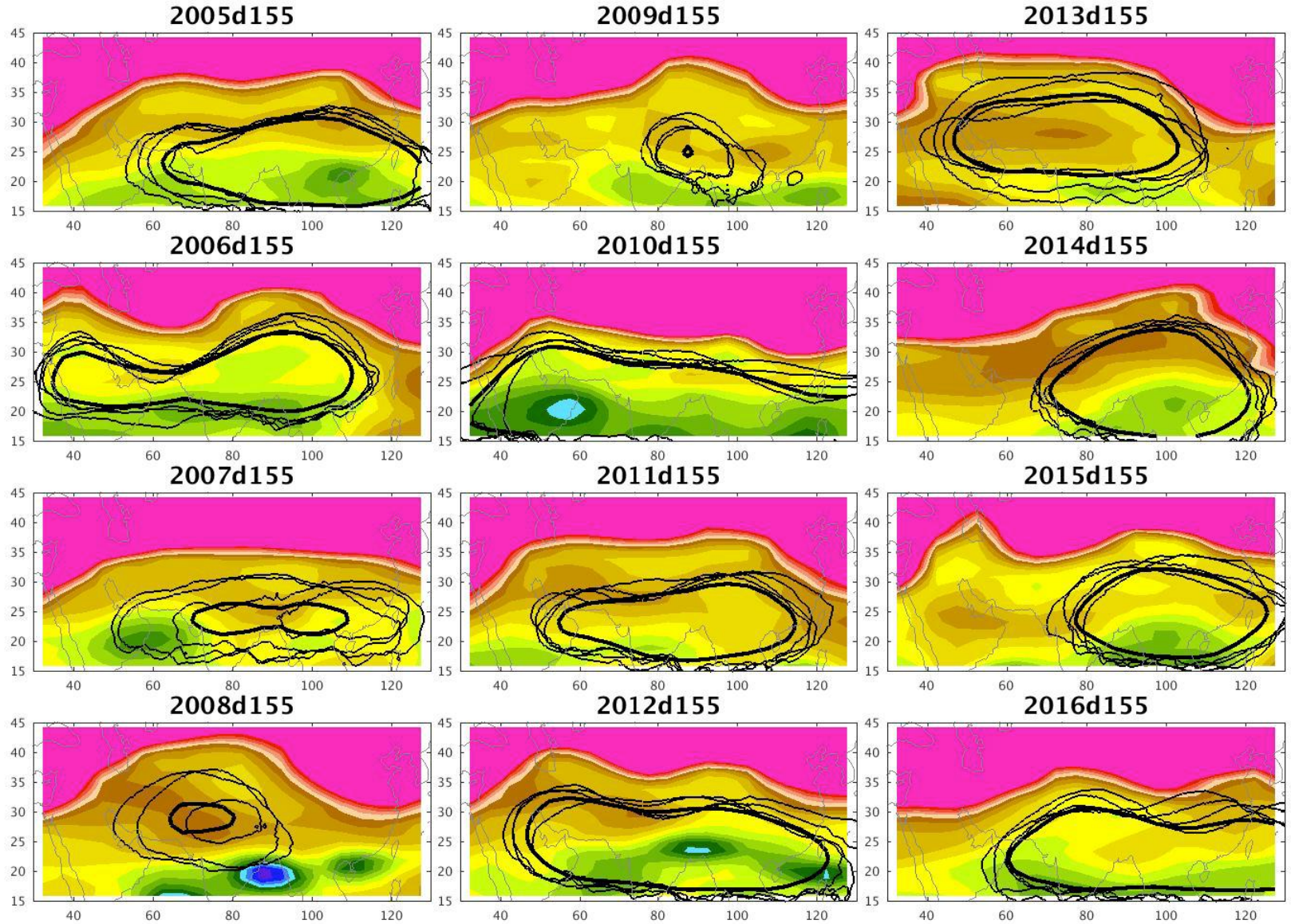
2005--2016

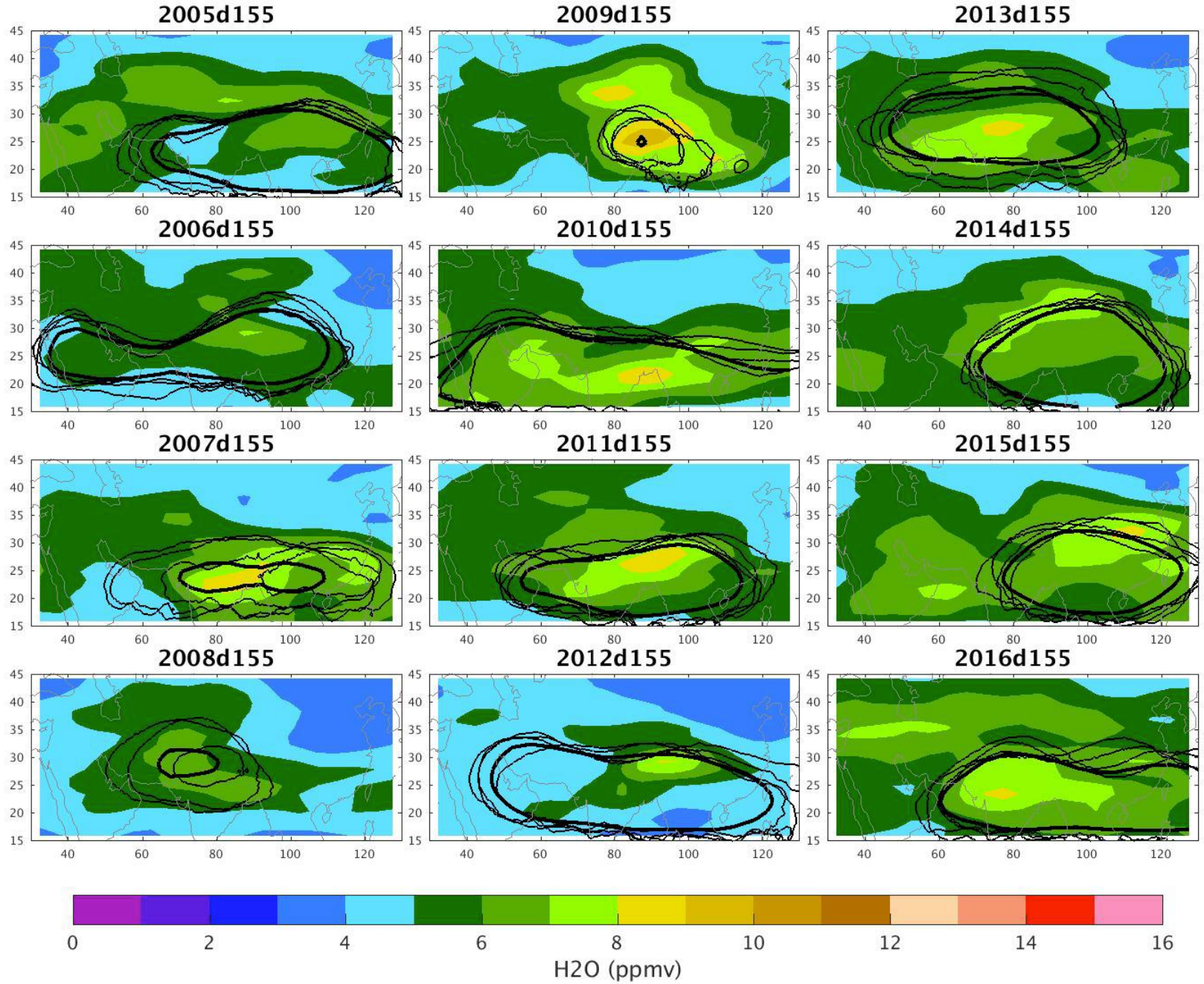


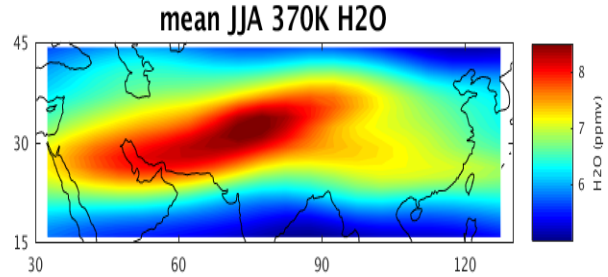
1980--2016

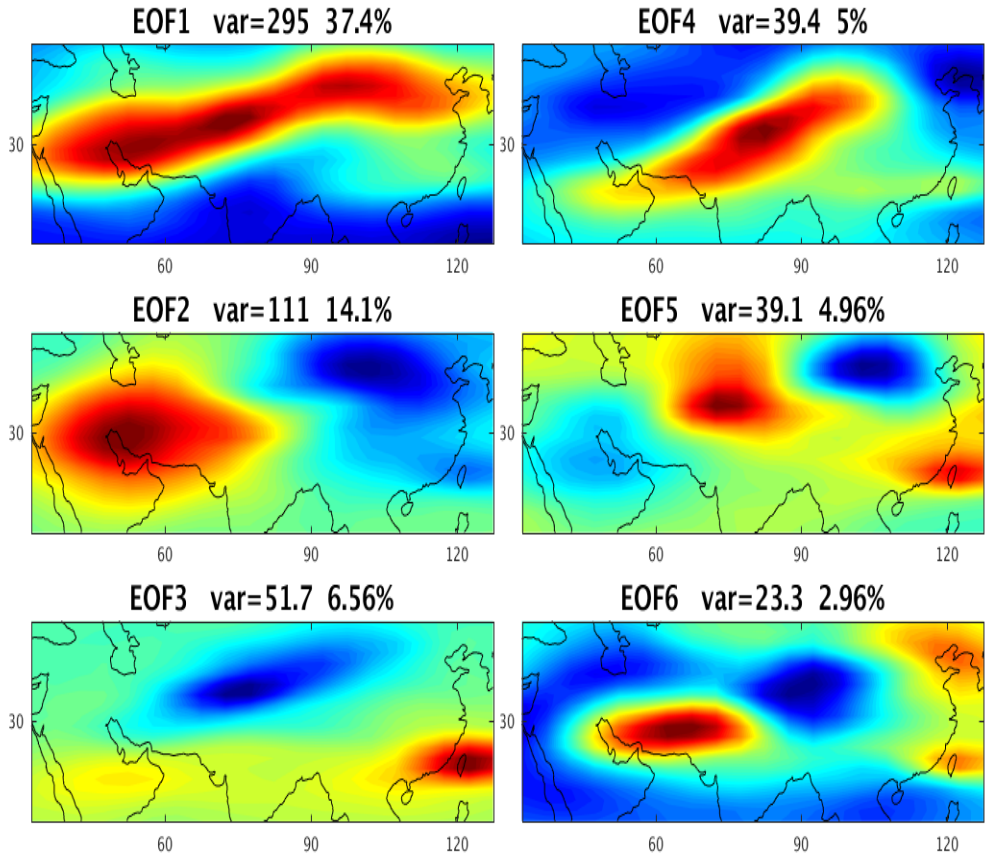


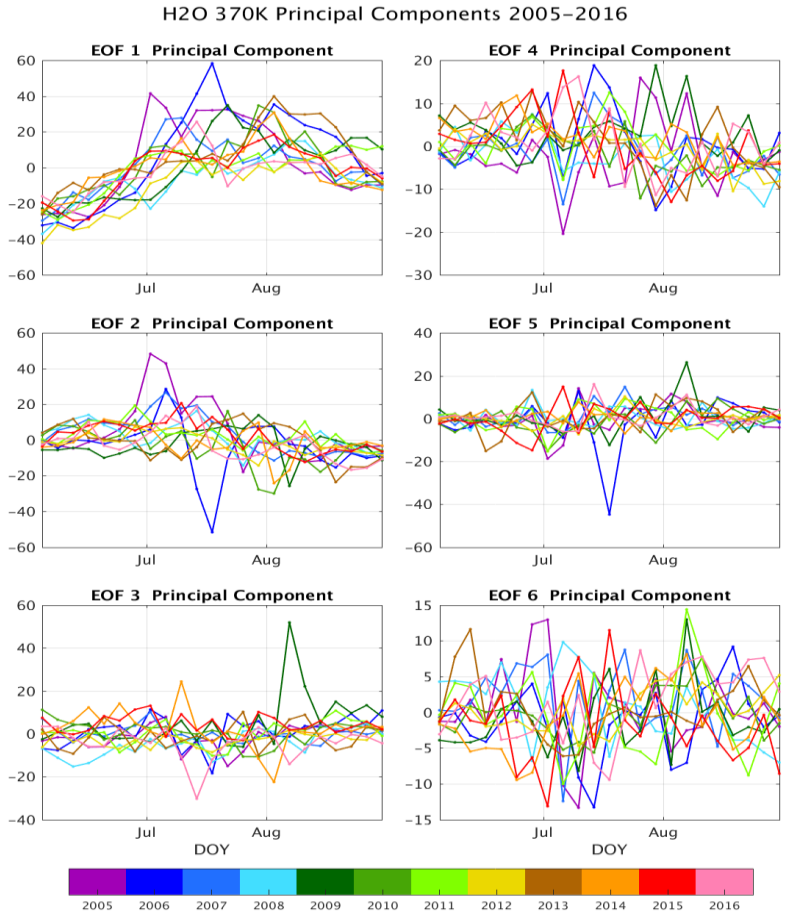
370 K O3 DOY 155 (04 June non-leap year) (Black MSF contour is 356500 m^2/s^2)

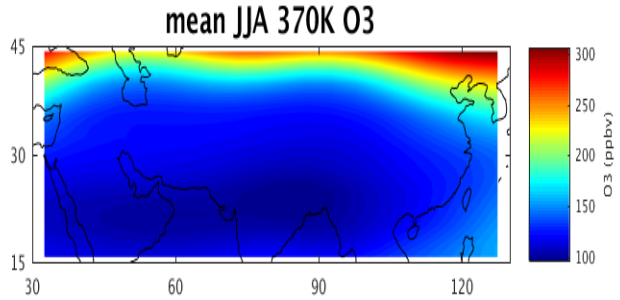


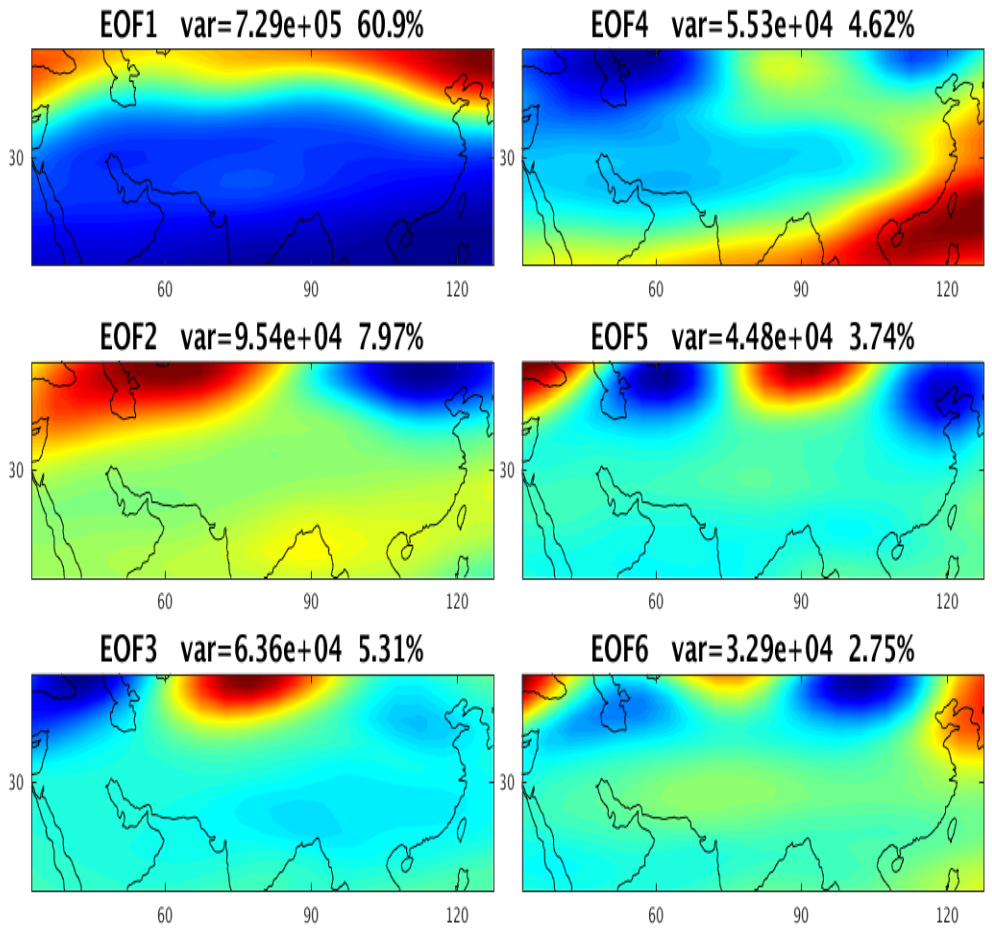

370 K H2O DOY 155 (04 June non-leap year) (Black MSF contour is 356500 m^2/s^2)
2005d155
2009d155
2013d155
2006d155
2010d155
2014d155
2007d155
2011d155
2015d155
2008d155
2012d155
2016d155
0
2
4
6
8
10
12
14
16
H2O (ppmv)

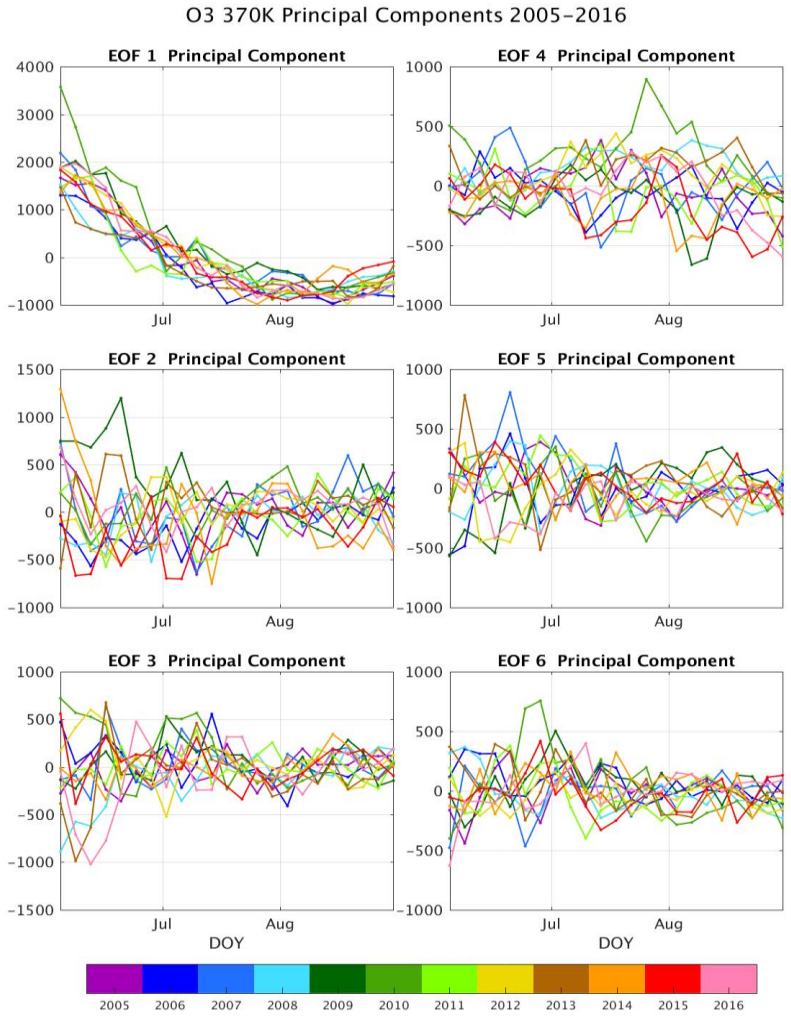

mean JJA 370K H2O
45
30
15
30
60
90
120
8
7
6
H2O (ppmv)

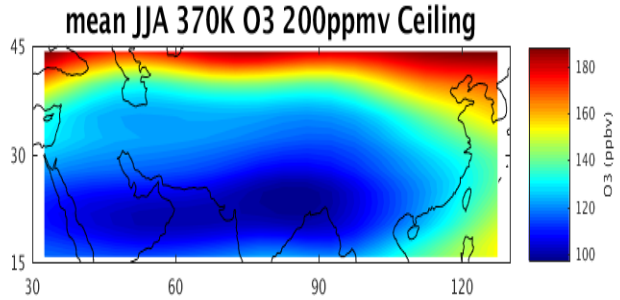

EOF1 var=295 37.4%
EOF4 var=39.4 5%
EOF2 var=111 14.1%
EOF5 var=39.1 4.96%
EOF3 var=51.7 6.56%
EOF6 var=23.3 2.96%
30
60
90
120

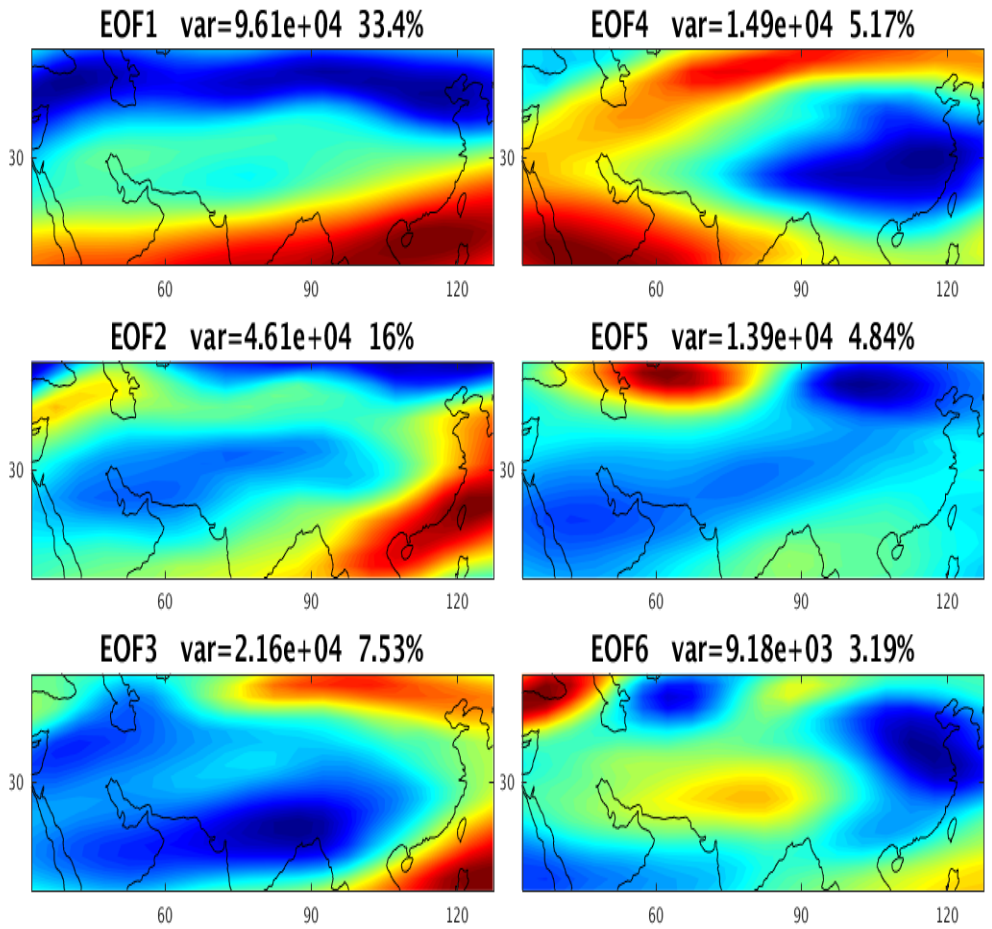

H2O 370K Principal Components 2005–2016
EOF 1 Principal Component
EOF 4 Principal Component
EOF 2 Principal Component
EOF 5 Principal Component
EOF 3 Principal Component
EOF 6 Principal Component
Jul
Aug
DOY
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

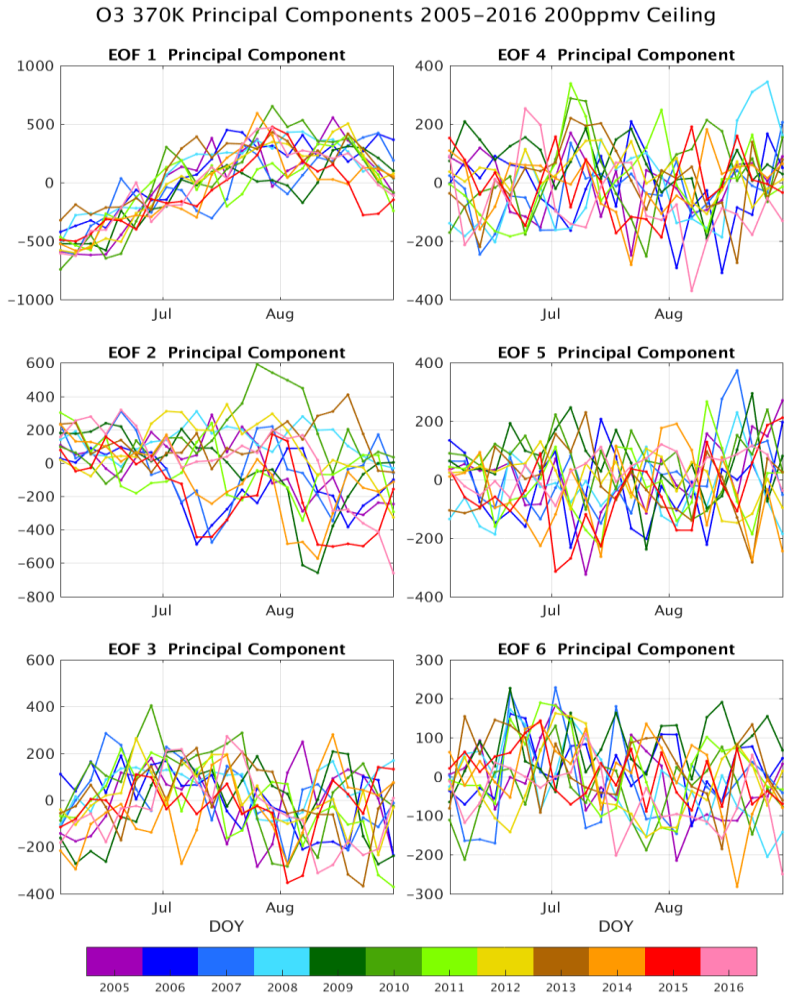

mean JJA 370K O3
45
30
15
30
60
90
120
300
250
200
150
100
O3 (ppbv)

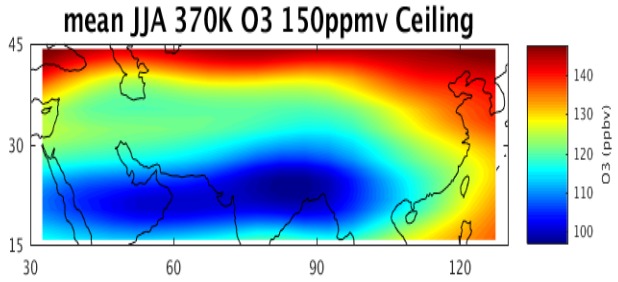

EOF1 var=7.29e+05 60.9%
EOF4 var=5.53e+04 4.62%
EOF2 var=9.54e+04 7.97%
EOF5 var=4.48e+04 3.74%
EOF3 var=6.36e+04 5.31%
EOF6 var=3.29e+04 2.75%
30
60
90
120

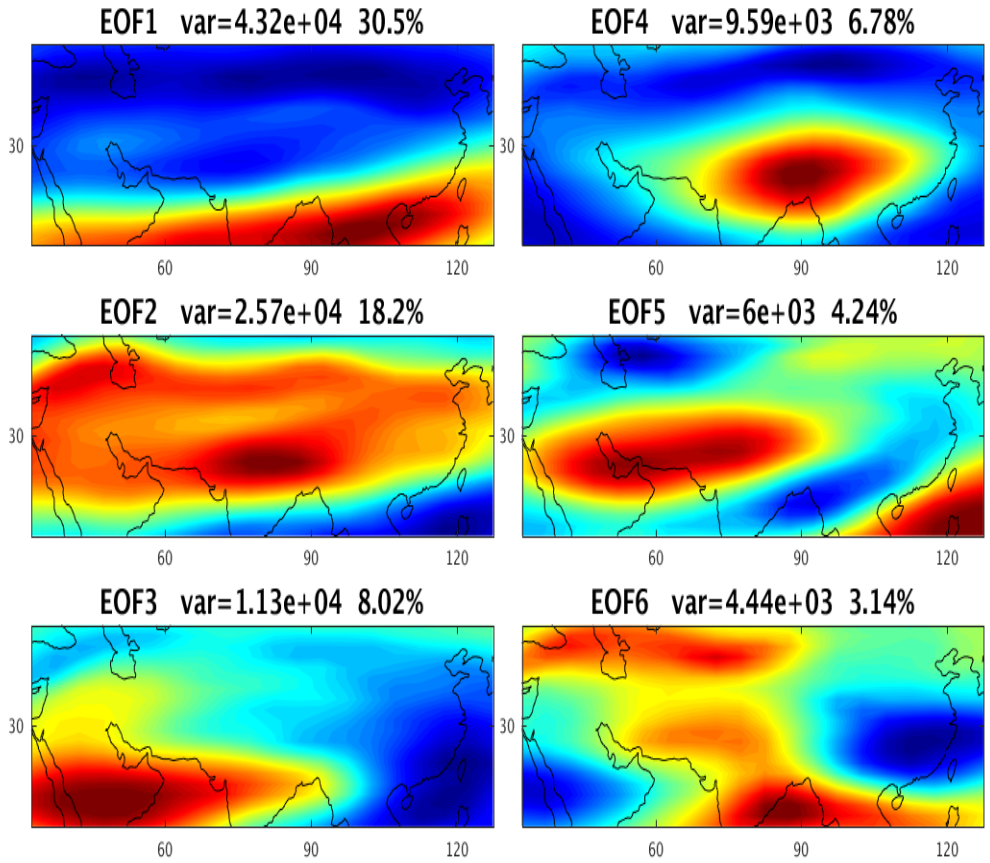

O3 370K Principal Components 2005-2016
EOF 1 Principal Component
EOF 4 Principal Component
EOF 2 Principal Component
EOF 5 Principal Component
EOF 3 Principal Component
EOF 6 Principal Component
Jul
Aug
DOY
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

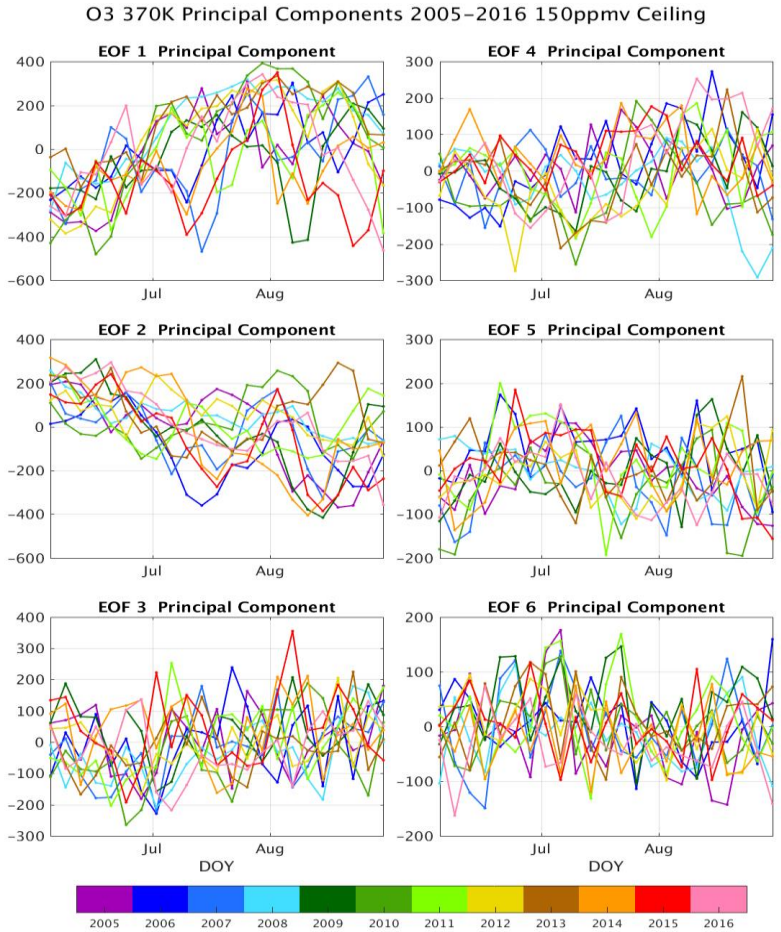

mean JJA 370K O3 200ppmv Ceiling
45
30
15
30
60
90
120
180
160
140
120
100
O3 (ppbv)


EOF1 var=9.61e+04 33.4%
EOF4 var=1.49e+04 5.17%
EOF2 var=4.61e+04 16%
EOF5 var=1.39e+04 4.84%
EOF3 var=2.16e+04 7.53%
EOF6 var=9.18e+03 3.19%
30
60
90
120


O3 370K Principal Components 2005-2016 200ppmv Ceiling
EOF 1 Principal Component
EOF 4 Principal Component
EOF 2 Principal Component
EOF 5 Principal Component
EOF 3 Principal Component
EOF 6 Principal Component
Jul
Aug
DOY
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016


mean JJA 370K O3 150ppmv Ceiling
45
30
15
30
60
90
120
140
130
120
110
100
O3 (ppbv)

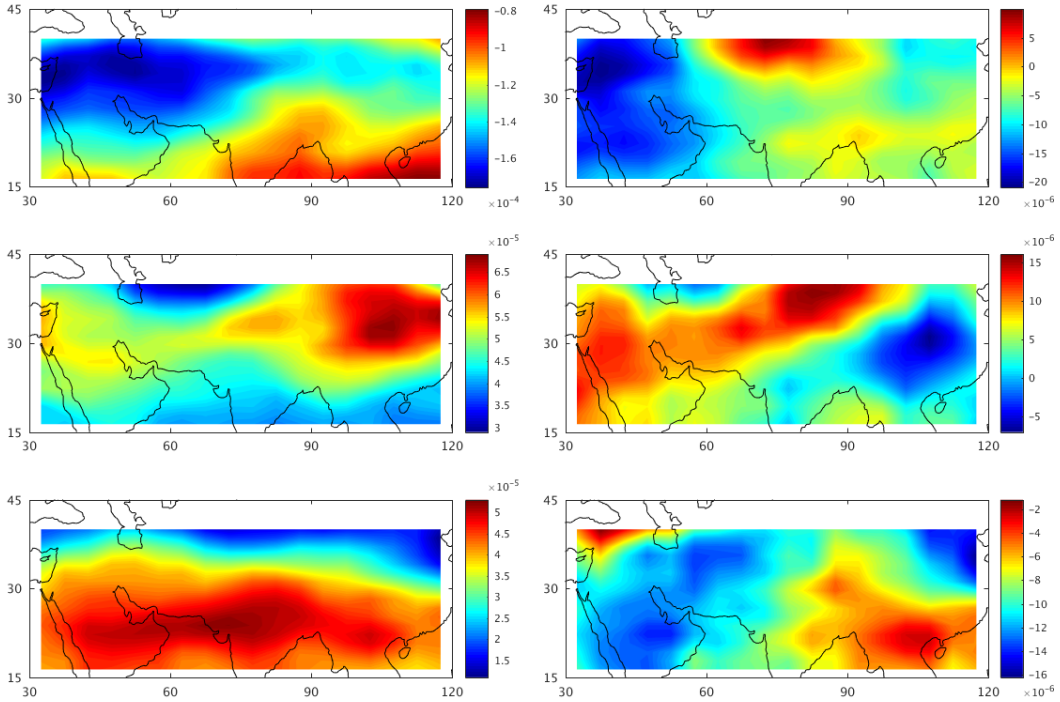

EOF1 var=4.32e+04 30.5%
EOF4 var=9.59e+03 6.78%
EOF2 var=2.57e+04 18.2%
EOF5 var=6e+03 4.24%
EOF3 var=1.13e+04 8.02%
EOF6 var=4.44e+03 3.14%
30
60
90
120


O3 370K Principal Components 2005-2016 150ppmv Ceiling
EOF 1 Principal Component
EOF 4 Principal Component
EOF 2 Principal Component
EOF 5 Principal Component
EOF 3 Principal Component
EOF 6 Principal Component
Jul
Aug
DOY
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Preliminary constituent correlation results with MLS CO

- Panels on the left are MLS CO weighted by the principal components of the panels on the right.
- In the next week I will stare at lots of these and see what kind of story I can tell.

MLS CO weighted by 370K MSF (test 5) principal components



370K MSF above 356500m^2/s^2